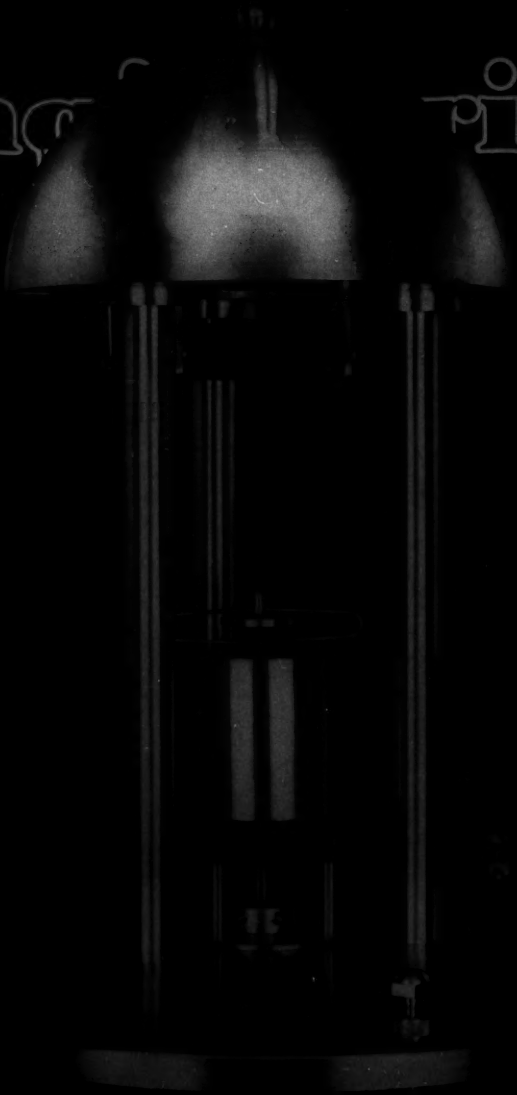
Electrical Engineering

March
1940



Published Monthly by the
American Institute of Electrical Engineers

To Measure—MOISTURE CONTENT
ELECTRICALLY

MOISTURE is an elusive agent—all-pervading in nature and difficult to detect, difficult to eliminate or control. And when there's moisture in supposedly dry annealing gases, high-carbon steel decarburizes and becomes unsatisfactory for many uses. Razor blades made from it have poor edges; automobile and airplane gears do not hold up in service.

To help eliminate this handicap, G-E engineers were asked to devise an instrument which would improve annealing and heat-treating operations by determining the moisture content of gases. As "Headquarters for Electrical Measurement," the G-E laboratories had already solved other tough problems for industry—had made instruments to measure lightning surges and the trickle of electrons in a vacuum, instruments to measure color exactly and instruments to unscramble sound waves; and now they set to work on measuring moisture.

The result was a portable potentiometer which measures the dew point, or temperature at which moisture will condense from a sample of gas. (It's described in Publication GEA-2630, which is yours for the asking.) The moisture condenses on a thin, metallic mirror connected to a thermocouple and then to an indicating instrument. An operator regulates the flow of the cooling medium against the back of the mirror until the exact condensation point, or dew point, is reached and temperature readings can be made. Thus, another measurement problem was solved.

G-E engineers have brought to electrical measurement the experience of fifty years in almost every field of electrical endeavor. That's why there are accurate G-E instruments to measure almost any quantity—current, voltage, resistance, watts, frequency, power-factor—in dozens of standard styles, indicating and recording, and in ratings to fill every need. If you have a problem that involves measurement, remember General Electric, Schenectady, N. Y., as

HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC

A30-153

Specify *Balanced* insulation on enameled wire

One good quality, alone, is not sufficient

THE ABRASION TEST is one of several standard tests which measure the Balanced Quality of enameled wire insulations

The abrasion tester applies a predetermined scraping load on the enamel film

High abrasion resistance in enameled wire is sometimes obtained at the expense of flexibility or other essential characteristics . . . . . The ideal combination is attained only in Balanced Insulation in which no quality is sacrificed.

• • •

HOW ABRASION RESISTANCE TESTS EVALUATE INSULATING ENAMELS

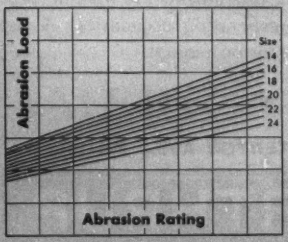
An abrasion test measures the resistance of any enamel film to the mechanical abrasion encountered by enameled wire in normal winding operations.

The Belden Abrasion Tester is a standard test instrument, perfected by Belden engineers, for applying an adjustable scraping load to the surface of a slow-moving specimen of enameled wire. By comparing the load required to force the scraper through the enamel film with the scraping loads shown in standard test curves, it is easy to determine whether the test specimen meets the requirements of "balanced" Beldenamel insulation. A separate comparison curve is used for each gauge of enameled wire since film thickness varies with wire diameter.

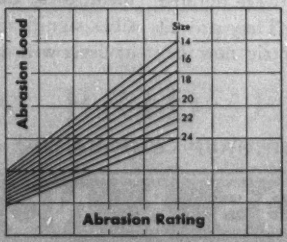
Making high temperature abrasion test

Similar tests are made on specimens placed in an electric oven to heat them to the temperatures encountered in impregnating and baking operations and in subsequent service conditions. Unless the specimen survives the standard abrasion load, the wire is rejected. Only "balanced" insulation will pass these abrasion tests. Every enameled wire user can make these tests and eliminate guesswork in buying "balanced" insulation.

Low Temperature Abrasion Tests



High Temperature Abrasion Tests



WHAT IS BALANCED INSULATION?

It is an enamel film which gives the best over-all performance in abrasion-resistance, flexibility, adherence, aging, solvent-resistance, etc.

To produce an enameled wire that will rate high in one or two of these qualities is easy. But, too often, to obtain these high individual ratings, other characteristics are sacrificed. For instance, an overbaked enamel may have high abrasion-resistance . . . but rate low in flexibility. Likewise, a very flexible film may not resist the action of solvents.

The ideal combination is found only in a wire with "balanced" insulation . . . like Beldenamel. Beldenamel is produced under such accurately controlled conditions that the essential electrical and mechanical characteristics are scientifically balanced with reference to each other. No one quality is supreme. All are combined to provide the most satisfactory results in your winding department . . . and in your finished product.

Do you want to know if you are getting Balanced Insulation in every wire shipment? Why not adopt Belden test methods . . . and be sure. They apply to any type of enameled wire.

Belden

Manufacturing Company
4638 W. Van Buren St., Chicago

Manufacturers of
Beldenamel—Silkenamel—Cotenamel—
Glass-enamel—Celenamel—and Formvar.

Further data on tests and instruments for rating characteristics of *balanced* insulation sent on request.

Twelve of the fourteen load recorders, and a frequency recorder

Load Distribution Is More Efficient

When It's Telemetered and Totalized

Load is distributed among Philadelphia Electric's six generating stations with the help of Leeds & Northrup Load Telemetering Recorders. Located in the System Operator's office, they show power generated by distant stations and also the interchange between interconnected areas. These recorders make it possible to load each station for highest overall efficiency.

The first six, installed in 1923, were the first load recorders L&N ever made. They proved so useful that Philadelphia Electric now has fourteen. And today, *after sixteen years, those six initial mechanisms are still recording load,* just as reliably as the latest additions.

Since that first installation in 1923, over 300 Leeds & Northrup Load Recorders have been installed for scores of power companies. Widely used to record power exchange between interconnected systems as well as distribution within them, these L&N instruments are making possible significant generating economies. A list of users will be sent on request.

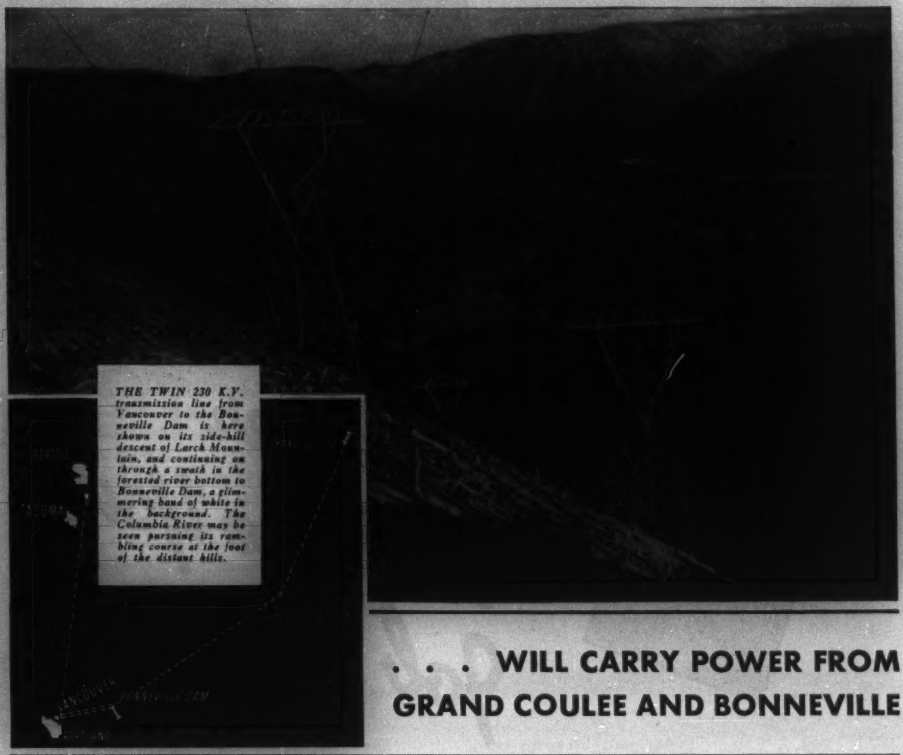
LEEDS & NORTHRUP COMPANY, 4962 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

Jnl. Ad. N-59-161(2)

450 MILES OF ROTATED TOWER LINE



THE TWIN 230 K.V. transmission line from Vancouver to the Bonneville Dam is here shown on its side-hill descent of Larch Mountain, and continuing on through a swath in the forested river bottom to Bonneville Dam, a glimmering band of white in the background. The Columbia River may be seen purling its rambling course at the foot of the distant hills.

. . . WILL CARRY POWER FROM GRAND COULEE AND BONNEVILLE

TOWERS of the rotated type have a distinguished performance record in the carrying of heavy loads over rough terrain. The project above, now under construction, will prove no exception.

It loops the Cascade Mountain Range in the state of Washington—450 miles of rugged, virgin country from Grand Coulee to Bonneville, thence to Vancouver, Tacoma and Seattle—a 230 K. V. transmission line for the distribution of power from two outstanding Columbia River projects, Grand Coulee and Bonneville dams. The more than 2200 rotated towers required for this line are under contract to American Bridge Company for the U. S. Department of the Interior, The Bonneville Project.

These towers are designed for extra heavy lines with especial consideration given to the character of widely variant and often hazardous topography. And, as usual in American Bridge practice, full size specimens have undergone the "acid test" in our Shiffler Plant test frame, where field loading conditions conforming to the specified design criteria were duplicated.

AMERICAN BRIDGE COMPANY

General Offices: Frick Building, Pittsburgh, Pa.

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UNITED STATES STEEL

Another TOOL to Make Your Job Easier . .

"HOT OFF the press!" Designed, like a slide rule, to save your valuable time. That's the new switch and bus insulator booklet issued by O-B. To select the type of station insulator needed for a particular application, you simply make a tentative choice from a two-page panorama which gives pertinent data for each unit, and then arrive at the final answer by referring to the detailed information on another page. Aside from this feature the booklet tells how to judge insulators, lists the advantages of pin-caps and station posts, and contains useful handbook data. O-B wants everyone interested in station design and operation to have this booklet. If you haven't received a copy, write for one today.

Ohio Brass (B)

MANSFIELD, OHIO U. S. A.

Canadian Ohio Brass Co., Ltd., Niagara Falls, Ont., Canada

Electrical Engineering

Registered U. S. Patent Office

for March 1940—

The Cover: A new instrument for time measurement uses as vibrator a wire kept in tension by a weight (see TRANSACTIONS pages 137–42).

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VOLUME 59 NUMBER 3

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

F. MALCOLM FARMER, President H. H. HENLINE, National Secretary

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Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

¶ Statements and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility.

¶ Correspondence is invited on all controversial matters.

High Lights • •

Engineering Education. The engineer obviously must learn and know the technical matter that is unique to his profession; but if more than mediocrity is to be his reward, then he must develop himself in a broad manner so as to be able to solve problems by weaving together technical data with social, economic, and psychological factors, says one engineering-college dean, who describes the program established at his institution to provide young engineers with this type of training (*pages 119–22*).

Unsolved Transportation Problems. A review of some of the unsolved problems facing electrical engineers of the transportation industry points to the need for a research organization jointly supported by the operating companies. It is believed that such an organization could solve these problems in much the same way that the Presidents' Conference Committee solved the problem of the obsolete trolley car by preparing specifications for the PCC car (*pages 113–17*).

Hoover and Edison Medal Presentations. Featured at the recent winter convention was the joint presentation of the Hoover Medal to Gano Dunn (A'91, F'12) and the Edison Medal to Philip Torchio (A'95, F'12). Addresses of the medalists and of Past President John C. Parker (A'04, F'12) who introduced Doctor Dunn, and Ralph H. Tapscott (A'18, F'29) who introduced Mr. Torchio, are published in essentially full text (*pages 95–102*).

Radio Noise. Transient conditions in an electric circuit set up fields which cause radio noise; for the measurement of such effects a joint committee of EEI, NEMA, and RMA has recommended certain instrument characteristics, and practices in making measurements directly from apparatus or along lines, collecting data for establishing radio-noise standards, and determining broadcast field-strength levels (*Transactions pages 178–92*).

Distribution in Buildings. Electric distribution systems in buildings may be designed to have considerably greater capacity than is required by the initial connected load, without any appreciable increase in total cost; this reserve capacity will enable the system to handle the additional loads likely to develop after initial installation and may avoid costly replacements (*pages 104–06*).

Bridge Networks. Much technical literature has appeared on the subject of bridge networks, which are of many types and which are used for measurements of numerous electrical as well as nonelectrical quantities. Users of bridges, students, and others interested in the subject may find useful a brief classification of various bridges, with balance equations for each (*pages 108–13*).

Earnshaw's Theorem. A century ago Samuel Earnshaw formulated the theorem that "a charged body placed in a field of electric force cannot be in stable equilibrium." In this issue, a physicist offers additional support for this theorem and shows its relation to two types of stable free suspension using magnetic forces (*pages 118–19*).

Time Standard. Using a wire kept in tension by a weight as the vibrating element, a new device for use as a secondary time standard may have an error of less than one-tenth second per day under favorable conditions; the frequency may be varied over a moderate range with precise control (*Transactions pages 137–42*).

Testing Arresters. Distribution lightning arresters that are removed from service may be tested and rehabilitated for further use for between 5 and 15 per cent of the cost of new arresters in ratings from 3 to 15 kv, according to a survey of the practices of a number of operating companies (*Transactions pages 142–9*).

Voltage Regulator. Essentially perfect regulation may be maintained by modern direct-acting voltage regulators by utilizing an inherent nonlinear property of the resistance elements, careful balancing of electrical and spring torques at every point in the range, and use of a stabilizing transformer (*Transactions pages 149–57*).

Train Control. An automatic block signal system with no visible block signals is used to control the movement of trains operating with small headway on the San Francisco-Oakland Bay Bridge; electrical equipment was chosen throughout in preference to nonelectrical mechanical devices (*Transactions pages 153–64*).

Cable Sheath. Production of sound lead sheath throughout a length of cable requires complete union of the successive charges in the cylinder of the lead press and the removal of impurities in the lead. Both mechanical and chemical methods are used in a new technique (*Transactions pages 165–78*).

Radio-Frequency Phenomena. A correlation between high-voltage phenomena at radio frequencies and at power frequencies has been observed in that the gradients at which high-frequency breakdown occurs appear to follow the same laws as 60-cycle corona (*Transactions pages 129–37*).

Engineers as Arbitrators. "Engineers as a class might well prove a fertile field for recruiting a body of competent, intelligent individuals to serve industry and labor in a neutral capacity in the adjudication of their conflicts" (*pages 102–03*).

Winter Convention. The detailed report of the 1940 winter convention appears in the Institute Activities section (*Pages 126–9*). It includes reports of the meetings of the committees on Student Branches, Sections, electrochemistry and electrometallurgy, education, communications, and sound. The technical conferences on electronic devices, test code for synchronous machines, definitions, and sound are also reported.

Nominating Committee. Meeting during the winter convention, the national nominating committee presented its ticket of candidates for national Institute offices (*pages 129–30*). Biographies of the candidates appear in the Personals section (*pages 131–3*).

Board of Directors. Appointments, meetings, and other matters of interest were acted upon by the Institute's board of directors at its regular meeting held during the winter convention (*page 129*).

Letters to the Editor. "The Use of the Millibar for Weather Bureau Reports" and a method of "Obtaining Test Constants for Induction Motors" are dealt with this month in letters to the editor (*pages 124–5*).

Television Tube. To meet the requirements of television, a 20-kw tetrode has been developed for ultrahigh-frequency transmitters; its design presented special problems (*page 107*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: a comprehensive article on the illumination at the New York World's Fair, with four-color illustrations; an article outlining trends in railroad motive power by Sidney Withington (F'24); an article reviewing the trends in the development of electrical apparatus for the generation, transmission, and distribution of electric energy by A. C. Monteith (A'25); a paper describing methods of controlling radio interference by C. V. Aggers (A'39); a paper on variable-voltage equipment for rotary oil-drilling rigs by E. H. Lamberger (A'27); a paper on the use of multiwinding transformers with synchronous condensers for system voltage regulation by H. P. St. Clair (M'29); a paper on the wave shape of 30- and 60-phase rectifier groups by O. K. Marti (F'39) and T. A. Taylor (M'36); a paper describing the Magne-Blast air circuit breaker for 5,000-volt service by E. W. Boehne (M'37) and L. J. Linde (A'39); a paper discussing arc-furnace loads on long transmission lines by T. G. LeClair (M'29); and a paper on the modernization of a transit system, with particular reference to the factors that determine the choice of vehicle, by G. L. Hoard (A'19).

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Copyright 1940 by the American Institute of Electrical Engineers. Printed in the United States of America.

Number of copies this issue 23,350.

Hoover and Edison Medals Presented at Winter Convention

GANO DUNN
HOOVER MEDALIST

"Distinguished public service" and "meritorious achievement in electrical science, engineering, or arts" were recognized by the presentation of the Hoover and Edison medals, respectively, to Gano Dunn and Philip Torchio, Fellows of the AIEE.

PHILIP TORCHIO
EDISON MEDALIST

PRESENTATION CEREMONIES for both the Hoover Medal and the Edison Medal for 1939 were held January 24, 1940, during the recent AIEE winter convention in New York, N. Y. The Hoover Medal, joint award of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE, was conferred upon Gano Dunn (A'91, F'12, past president, Edison medalist) president of the J. G. White Engineering Corporation, New York, and of Cooper Union for the Advancement of Science and Art. Philip Torchio (A'95, F'12) retired vice-president, Consolidated Edison Company of New York, Inc., received the Edison Medal, highest honor of the AIEE, for "distinguished contributions to the art of central-station engineering and for achievement in the production, distribution, and utilization of electric energy."

Doctor Dunn's attainments were described by Past President John C. Parker (A'04, F'12) vice-president, Consolidated Edison Company. John V. W. Reynders, past president, AIME, and chairman of the Hoover Medal board of award, presented the medal to Doctor Dunn, with the citation, "Long honored by his fellow engineers for professional achievement, he has, beyond that, exemplified high civic purpose and a devotion to public service which have earned for him the Hoover Gold Medal for 1939."

The history of the Edison Medal was reviewed briefly by L. W. W. Morrow (A'13, F'25) chairman of the Edison Medal committee. The achievements of Medalist Torchio were described by R. H. Tapscott (A'18, F'29) president, Consolidated Edison Company of New York, Inc., and presentation of the Edison Medal was made by President F. Malcolm Farmer. The addresses of Doctor Parker, Mr. Tapscott, and the two medalists follow in essentially full text on this and succeeding pages.

Gano Dunn—1939 Hoover Medalist

JOHN C. PARKER Past President AIEE

From time immemorial it has been the custom of social groups to appraise their most distinguished members and in one way or another to declare to the world their appraisals. It is peculiarly fitting that in a period in which, with increasing emphasis, the engineering profession has been discussing the social status of the engineer, we should address ourselves to the granting of the Hoover Medal to one who, in the highest sense, represents the qualities held in esteem by his colleagues.

The granting of such honors fulfills a threefold function. In the first aspect it is a declaration to the recipient of the esteem in which he is held by his colleagues, then internally to the group it serves as a confession of its ideals, and last, but not least, it pronounces to the outside world those qualities of mind and of character which the group collectively most values and of which it deems the recipient to be a signal exemplar.

The medalist, Doctor Gano Dunn, has received so many and so notable honors that we can add but little to his fame by this most distinguished award; we can and do draw aside for a moment from our routine tasks to consider the qualities of one whom, without envy, each of us would strive humbly to emulate; we can, and do, by our act here this evening, declare to the lay world those qualities of person and those achievements in one of our members by which we would like the world to know our profession at its finest development.

We start with the conception of engineering as based on the physical and mathematical sciences. A kindly and tolerant predisposition toward science is not enough in a great engineer; he must have a profound understanding and a creative attitude toward the fundamental sciences in all their ramifications and in their applications as well.

Our ideal engineer will not rest content with mere scientific exploration. He will be of a practical mind and will force his science realistically, through invention and design, to serve the purposes of men. This he will do in a practical world governed by economic law. He must be a realistic economist.

His engineering must be carried through, co-operatively with men of diverse minds and interests, for the service of the society of which he and his profession are components. This means that he must have broad and understanding social qualities. These qualities cannot be of the mind alone, nor can they stem merely from conscious policy. They must derive from the spirit of the man. His inflexible honesty can never become self-will; his clearest thinking will be adaptable; his contacts with men of lesser endowments will be modest and patient.

This ideal engineer, proud of the attainments of his profession, devoted to its fascinating technique and purposefully giving himself, co-operatively with other men, to a realization of that technique in and for the service of society, still will know that, important—essential—as it is, it is not all that there is in life. So he will devote himself to those good things outside his profession which make for a society so well rounded as to enable men of other interests the better to live their lives, and themselves, in their own preferred way, to be a part of the human family.

Because Gano Dunn has been to his fellow engineers an example of these qualities which in their full development can make our profession great, we join to affection a sense of deep obligation to him as our gentle and self-effacing standard bearer.

The board of award says, "The medal signalizes great unselfish nontechnical service by engineers to their fellowmen." While the emphasis is on the broader service, it is none the less on service rendered not in lieu of but above and beyond the full measure of engineering attainment. Implicitly, the latter is a primary, though not the ultimate criterion. There is no need here to review Doctor Dunn's scientific and professional attainments. Not only are these well within the view of his fellow engineers, but on the occasion of other honors that so deservedly have come to him they have been set forth in detail. On this occasion we concern ourselves with those things for which he is esteemed by his "fellow engineers for distinguished public service."

The Hoover Medal

Because Doctor Dunn has combined a great love and reverence for his profession with high vision of its social value, it was natural that he should seek to compel his corporate engagements to serve the broad ends of society, making of them something vastly greater than business enterprise. It is in this spirit that he has directed the activities of the great corporation of which he is chief executive into a diversity of services to the nation, to our neighboring republics, and on other continents.

It is not without significance as to the broadly human interests of this man that, as mentioned at the time of the conferring on him by the AIEE of the Edison Medal, service to the fine arts, as exemplified in the renovation and redecoration of the Metropolitan Opera House, was within the scope of his organization equally with the design and execution for our government of so various projects as nitrate plants, steam generating stations, and government aviation terminals.

More personally perhaps, but still within hailing distance of his engineering interests, Doctor Dunn has himself conceived many projects for broadening the service of science and technology to mankind. Equally he has been willing generously to participate in the work of others whenever worthily addressed to human betterment.

It was in character that he should take a large part in the organization of the Engineering Foundation of which he was the first chairman, and of the National Research Council of the National Academy of Sciences, of which he was chairman for five years in the late 20's. His presidency of the United Engineering Societies, of the AIEE, and of the New York Electrical Society were characterized by effective effort to make these organizations more fully serve humanity.

Going further afield, his chairmanship of the building committee of the National Academy of Sciences, his service as a member of the War Department Nitrate Commission and as chairman and disbursing officer of the special committee of the State, War, and Navy Departments on submarine cables, and as a member of the engineering committee of the Council of National Defense during the World War are typical of the way in which he has found a broad field for the devotion of engineering to the public welfare.

For many years he has been chairman of the visiting committee of the National Bureau of Standards, and in 1936 he represented the State Department on the executive committee of the World Power Conference. He serves the country as a member of the Patent Office advisory committee. Under presidential appointment, he served as a member of the Science Advisory Board. He is also a member of the business advisory council of the Department of Commerce.

No national boundaries limit Doctor Dunn's effort to make science and engineering serve mankind. As vice-president of the International Electrical Congress of Turin in 1911, as an officer of the International Electrical Congress in St. Louis, as official delegate of the United States Government to the Second Pan-American Scientific Congress and to the Third Pan-American Commercial Conference, he has reached beyond the boundaries of our land. Reciprocally at home he serves as honorary secretary for the United States of The Institution of Electrical Engineers of Great Britain.

This conception of social obligation, this high vision of his profession as a very human thing naturally find expression in fields removed from the merely professional. I mention in passing only a few.

Under the recent appointment of the President, he serves as a member of the President's committee on civil service improvement, and by Mayor La Guardia he was recently appointed consultant to the New York City Housing Authority.

I need not recite to you his services to education beyond mention of his trusteeships in Barnard College, in Columbia University, and his presidency of Cooper Union for the Advancement of Science and Art.

These few of his many services are presented not as a catalog but as a refreshment of your memories. All of you know the devoted and unsparing service which Doctor Dunn gives to any activity with which he becomes identified. The devotion, the work, the fine wisdom which he brings to bear on his every activity, in and of themselves, would be enough, but greater than these, I believe, is the quality of the man himself, a quality which enriches every phase of life in which he participates.

It is interesting to speculate as to the influences that have made our great men what they are. I suspect that no one, not even the man himself, can ever quite appraise the weight of heritage and environmental influence in the formation of character.

Why, under a given set of influences, one man becomes hard and inflexible and another gentle and tolerant, why one becomes soft and another firm, we probably never fully will understand, but knowing that some, like the medalist of this evening, have done so well for the world through themselves, we have no excuse but to make our own environments and our own opportunities serve in ourselves as he has done to make life better for our fellows.

Was it from his paternal grandfather, Nathaniel Dunn—"a passionately devoted scientist and inventor, college professor, poet and author"—was it from the circuit riders two and three generations back on the maternal side, that he derived his inspiration and guidance?

How much of human understanding and of kindliness was induced by the frustrations of his plan for his collegiate career and by the fact that his course in the College of the City of New York was supported by the modest work of a night telegraph operator? How much of kindness and direction in his living came from contact in the post-graduate school of electrical engineering at Columbia University with the late Francis B. Crocker and Michael I. Pupin? These things we do not know, nor do we know why this man, from whatsoever sources, derived a sense of obligation, a kindliness, a patience with ordinary men, a nice regard for their rights and feelings, an integrity, and a sense of fairness which are the stigmata of the gentleman.

An old friend of Doctor Dunn, himself a fine embodiment of those qualities which make best for human service, Doctor Frank B. Jewett, recently wrote me of him: "He is patently honest and fair and without that pride of opinion which causes so many men to adhere to a false opinion merely because one has been expressed without full knowledge of the facts. . . Never once have I seen evidence that this point of view was in any way warped by the slightest tinge of mean or petty self-interest, either personal or in behalf of the group he represented. Always he has seemed to keep clearly in mind the necessity of reaching a final conclusion which incorporated fully the fundamental best interests of every one."

On behalf of the board of award consisting of representatives of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and American Institute of Electrical Engineers, the Hoover Medal is being awarded to Doctor Dunn.

This is a noble award and I know how profoundly in his great gentleness of soul he will appreciate the approbation of his fellow engineers. Greater than this award and the other notable honors that have come to him, greater than the recognitions through appointments to public service, greater than the honorary degrees that have been conferred on him by distinguished institutions of learning, he wears the ornaments of mind and character not as external habiliments put on to be seen but as the full flower of an inner spirit by which we would that men might always know the engineer.

Public Service

GANO DUNN, Past President AIEE

Some of the greatest controversies of today revolve around the question—what is public service and how should it be performed? There are those who regard it primarily as the service a government renders to its people, and there are those with a broader view who regard it as service rendered to the people, whether by government or by private agencies.

The public service rendered by government starts from a minimum under the old Jeffersonian ideal that that people is governed best which is governed least, and ranges through intermediate values to the other extreme represented by the totalitarian governments of Europe with a climax in Russia, where few of the activities of life escape government intrusion.

But I am not attempting a discussion of the relative merits of socialism, which, in the language of Doctor Nicholas Murray Butler, would wreck the efficiency of society in order to redistribute its discontent. Nor am I here eulogizing our own representative democracy based on the consent of the governed, with the government's power strictly limited by a Constitution and a Bill of Rights.

I do mean to point out that in our democracy the volume of public service rendered by private agencies is vastly greater than the volume rendered by government. The corner grocer who for our convenience and his own support provides a stock of food is rendering a public service, as is also the great insurance company which takes our savings and cares for the loved ones we leave behind us. These services are no less public services than are those of the post office, for instance. In fact, the whole realm of commerce and the arts, the ministrations of the professions and the church, and by far the major part of all the activities of our daily lives which the division of labor has assigned to us as our share of the privilege of living constitute public service rendered by private agency.

Although the aggregate of government public service is vastly less than that of private public service, the units through which government service operates are usually larger than the units of private public service,

notwithstanding the great size of certain private corporations which operate on a huge scale in industrial, financial, charitable, and educational fields.

Some of the most acute political issues of today in this country are joined over the question whether government public service is more efficient than private public service, and whether certain public services now rendered by private agency should be transferred to government.

If we analyze the Jeffersonian dictum that that government is best which governs least, we shall see that it means that the happiness of the people is best secured where there is a minimum of that kind of public service which is characterized by authority and force of law, and a maximum of that kind which, although regulated by government, is left to the initiative and internal administration of private agencies. Applying this criterion to the nations of the world, we shall not have much difficulty in discerning where happiness is at a maximum and at a minimum.

In our ordinary conceptions, the fact that all government activity and the major part of all private activity in public service is not prominent in our minds when we use the term public service, because public service of the kind that government employees render and a large part of that which the rest of society renders is balanced and paid for by economic compensation. It is the means by which we earn our living, and for earning one's living one should receive no more credit than that which goes to the performance of appropriate duty to the conditions under which we earn it.

Public service, as the term is usually used and as I shall use it hereafter, has come to have a more special meaning, which is the meaning given to it in connection with the Hoover Medal. It is applied to the service of those men and women who render to the public a service over and beyond that for which they are paid, a service which they render on account of love of their fellow men, and the satisfactions that come from doing something well, for the love of doing it rather than for the pecuniary reward it brings.

One has only to look around him to find public service of this kind on every hand, both in and outside of the government, to an extent that evokes the profoundest admiration, and re-establishes a sometimes faltering confidence in the capacity of human beings to live for unselfish ideals.

There is a complaint among engineers that their status as constituting a profession is not adequately recognized by society in general, and that their participation in public service in the special meaning of the term is not large relative to their numbers, nor in proportion to the participation of merchants, bankers, lawyers, doctors, and other individuals.

In the early days this used to be true, but I think the public service of engineers is now larger than they realize, both in the field of their technical services and in the broader fields of human relations outside of these. The background of an engineering training and equipment enables a valuable approach to other types of problems, which causes engineers to be drawn into civic, educational, and other activities outside of engineering work.

It is certainly a fact that engineers universally recognize the honor of public service and long to increase their own contribution to it. If they did not always feel this way, it is because the astonishing multiplication of great scientific discoveries and their economic application to the purposes of civilization, which is the field of the engineer, have in the past so absorbed and enchained engineers and given them such satisfactions and pecuniary rewards within their own profession, that neither in the processes of their education nor in the exercise of their tastes did they see the importance nor realize the joy and advantage of devoting to their relation to society as a whole more than a fraction of the attention which they devoted to their own fascinating art.

But all this has been different in recent years. As a result of growing recognition on the part of leaders in engineering education, the great engineering schools have, at the expense of diminished technical specialization, enlarged those areas in the education of engineers which tend to equip them for more useful and satisfactory places alongside of other men, not only in their own technical fields, but in the fields outside of them, into which engineers are more and more drawn.

The establishment of departments of humanities in our engineering schools, where history, languages, and the social sciences are now regarded as part of an engineering education, has been universally welcomed by engineers, and in no case that has come to my attention has the movement in this direction been reversed.

The very existence of the Hoover Medal "for distinguished public service", founded by Conrad Lauer and instituted by the four great representative national engineering societies, is an indication of the extent of the appraisal by the engineering profession as a whole of the high privilege it is for an engineer to contribute beyond as well as within the activities of his profession voluntarily to the service of the public, in emulation of such service by Herbert Hoover, the Medal's great exemplar, by Ambrose Swasey who founded the Engineering Foundation, and by John F. Stevens who saved millions of lives in Siberia.

The honor of this medal and the encomiums that have been heaped upon me I do not deserve, because of the little that I have accomplished in voluntary public service. But I have had a joy in laboring in that vineyard which nothing can express. I believe that the large number of engineers now similarly experiencing the joys of voluntary public service will increase rapidly, as the training and ambitions of engineers more and more make them available, and as the community comes to recognize in the engineering profession a vast untapped reservoir for public service.

Through such service, as well as through the practice of their profession, engineers will increasingly come to win their spurs and the honored place in the community along with other men, which they are now increasingly eager to fill.

In connection with such voluntary public service, it should be pointed out that it is not always the engineer who determines whether he shall take part in it. It is rather the community which adjudges his personality and quali-

fications, and invites him in if it feels he is competent.

More is necessary on the part of the engineer than a desire for public service. He may have this to a large degree and yet for lack of an adequate culture or the qualities of a judicial temperament, or for the lack of tact, he may remain uninvited.

A bar which also frequently prevents public service on the part of engineers otherwise well qualified is the peripatetic nature of their calling in some of its branches. The lot of the civil engineer is largely cast far from home, to the detriment of roots which other types of engineers are more likely to strike into the soil of their community, with public service as one of the fruits.

Engineers are not all of one mold, and just as poets are born and not made, so are great inventors and similarly great engineers. There are engineers with gifts for the conception of design and others with gifts for force and order in administration, some with minds for mathematics, and others intuitive to the geometric distribution of material masses. While they all have a common characteristic, in that they apply the scientific method of thought to whatever their problem may be, their personalities and qualities are so varied that generalizations about them as a class are not reliable. But in common with the great unifying principle of the scientific method of thought which binds them together, they have to a remarkable extent the endowment of another great gift, a love of truth, which springs from their contact with the laws of nature and is an outgrowth of the tastes which led them to become engineers.

Society welcomes such equipment, and as the march of scientific discoveries continues and national life becomes more complex, there is no doubt in my mind that the future holds wider open than ever to engineers the high honor of public service.

Philip Torchio—1939 Edison Medalist

RALPH H. TAPSCOTT, Fellow AIEE

Quite aside from the intrinsic fitness of the medalist, there are associated reasons why this year's Edison Medal award is particularly appropriate. The medalist has spent the greater part of his life actively in the employment of the company which derives from Mr. Edison's initial electricity supply undertaking. His earlier years were spent in the vicinity of and his technical education was received in the town of a pioneer development of Mr. Edison's system of generation and distribution. For many years he was a colleague of the 1923 Edison medalist, the late John W. Lieb, a former President of the Institute. In a very real sense it must be said of him that his lifetime was devoted to the realization, perfecting, and adapting to changing conditions of the work initiated by the great pioneer inventor and engineer whose work and memory this medal commemorates.

In the United States, in which the electric arts have so brilliantly and so extensively been developed, we are likely to forget how much of their origins are in the older world. There is for us electrical engineers a peculiar tie between the home of the medalist's maturity and his native country. As we have a precious heritage in the work of Galvani and Ferraris; as we have drawn from the ceramic industries of Italy; as we find ourselves honored to number among our members the Milanese Semenza, Pirelli, and Emanueli, whose work has enriched American engineering practice; as our profession further has been strengthened by the migration to our shores of eminent engineers and inventors like Marconi and Faccioli, so we have a further debt to that ancient but vital land in the work here of her son, Philip Torchio.

Forty-five years ago this month, he became identified with the light and power industry here in New York City.

It is impossible for most of us to visualize the real condition of the light and power industry of the early 90's. Certainly we know it was in its infancy; its tools had not been developed; there were many widely differing opinions as to its possibilities. Probably more time and thought had been devoted to the use of electricity as a convenience than to the economics of the industry as it exists today. Without belittling any of the discoveries and experiments at that time, let us say that generation and distribution were largely direct current; load was not only growing at a rapid pace but the requirements of distribution distances already had exceeded the limits of this method of generation and distribution.

That was about the state of the industry when Philip Torchio arrived from Vercana, Italy, in 1893 after his graduation from the University of Pavia and the Royal Polytechnic of Milan. First entering the employ of the Sprague Electric Elevator Company, he became associated with the Electric Illuminating Company of New York, one of the forerunners of the Consolidated Edison Company, in 1895. He was not alone an inventor but an engineer and an economist who took up the task of preparing the industry for its future growth. A-c generation and transmission were becoming the necessities of the business. The few small d-c generating stations in New York City had to be replaced by an a-c station with its transmission to substations for conversion of direct current throughout the city. It was through his analysis and co-operation with the manufacturers that it was possible to maintain underground transmission cables operating at 6,600 volts, and 25 years later these same cables were satisfactorily operated at 11,000 volts; but the continuity of the new system of generation and conversion was not as satisfactory as the direct use of d-c generation, and stand-by storage batteries became a necessity. Here again it was through Torchio's analysis that the present type of low internal resistance storage batteries, with the possibility of a high rate of discharge with a very low voltage drop, came into being.

But let us look for a minute at some of the controversial questions which were so rampant in those days. All of you know the difference of opinion which existed between the d-c and a-c proponents for normal distribution purposes. As alternating current became the standard for transmission systems, the question of frequency was the topic of the day. Should there be two frequencies—one

for conversion for d-c distribution and railway electrification, another for general commercial and residential use? Or should there be a compromise standard for the country to serve both purposes? In those days, systems were sprouting up at all sorts of frequencies—25, 40, 50, 60, and 125 cycles. Abroad, for successful railway purposes, the frequencies were even lower. In America, railway systems were generating at 25 cycles, either for single-phase use or for conversion to 600 volts; and although they were growing faster than the light and power companies, Torchio early foresaw the time when the operation of these two projects would be merged, and, again by his analysis of the existing conditions and the future, determined upon the 25-cycle system for all synchronous conversion purposes, either Edison direct current or railway use, and a 60-cycle frequency for those systems serving normal commercial and residential uses. As we look back, we realize that had a compromise frequency of say 40 cycles been adopted for the metropolitan territory, the necessary change-over to today's standard would have been a serious economic waste.

As the capacity of the systems grew, the problems of short-circuit currents assumed increasing importance. Torchio was among the first to adopt the use of reactance coils and to improve their mechanical design; but he also developed a fault detector and later a bus protector to limit further the effect on a system of a short circuit or ground on an individual feeder.

He has been granted patents on reactors, circuit breakers, fault detectors, protective devices, cable insulating methods, and cable joints; but the system developments of the past 40-odd years have been due more to his insistence and co-operation with manufacturers on the improvement of their protectors, their cable, and their large generators than upon the individual patents granted in his name.

The Edison Medal

These are a few of the objective achievements of the medalist. For us who are gathered together here tonight to do honor to him, the record is something more than the things he has done, however excellent they may be. The real import of the man and of his career lies in the personal qualities that led to his performance. Other men with equally good preparation entered the industry in the early years of the last decade of the last century. Some of them have left their mark on engineering development. Others have been content to accept what they found and to let natural growth take its course. Torchio has never been gaited that way. There is in his make-up no such thing as "good enough." Of himself and of his work he has demanded not only a high level of attainment, but always a higher and higher level. He has known how to set standards of perfection and then has been realist enough to strive in a practical way for a rational approach to those standards. It has not been enough for him to visualize an ideal, but rather with a burning enthusiasm, interestingly in the Edison tradition, he has ever striven toward it.

Often the absolute perfectionist, realizing the impossibility of ideal attainment, gives up and accomplishes nothing. Not so our medalist. The fact that the full standard of perfection is unattainable is to him a challenge to come as near to that as is feasible.

Nor has he been content roughly to outline his standards in broad general strokes. Rather he has insisted that no detail, so long as it is essential, is too unimportant to demand the best of thought and of performance. In some men this meticulousness can degenerate into mere fussiness. In all his operations, Torchio has had a nice sense of balance between those details, the soundness of which was essential to large objectives, and those attractive but dispensable ones, the overprosecution of which might divert from the end sought to be attained.

I have said that of himself he has always demanded a higher and higher level of attainment. Many of us, most of us perhaps, having done somewhat well in bringing forward our work, remain content with what has been achieved. To Torchio a high level of pioneering accomplishment has always served as a stimulus to push forward the frontiers which he himself has established. This is rather clearly revealed in the way in which, by progressive steps through his years of service with his company's system, he has sought every opportunity consistently with dependable service and sound economics further to advance the level of transmission voltages, finally finding expression in the introduction into American practice of 132-kv underground transmission of a character which has given excellent confirmation of his sound operating judgment and fine administration of technical detail.

Torchio is no narrow specialist. While his work has best been known because of his contributions to the transmission and distribution art, particularly with reference to underground circuit construction, the few specific references that already have been made give illustration of a breadth of interest more fully confirmed by the list of titles of his contributions to the literature and even better recognized by his immediate associates. From system planning and frequency selection and interrelation of diverse types of prime movers, through switchgear, transmission and transformation, distribution and metering, he has extended his interests and his creative contributions to the apparatus of utilization, never, for all of the diversity of his interests, abating from the exacting standards of thoroughness that he established for himself.

Always he has recognized engineering as an adjunct of economics, and so, in forming and giving direction to his technical work, it was but natural that he developed a

vital interest in that economic balance without which engineering can become mere technique.

Realizing that his engineering and economics exist for execution by human beings in the service of the community, he moves on into a wider range of interests.

He was the originator of a group insurance plan for corporations which he submitted to the large insurance companies in 1910 and which has become quite universally adopted since that time.

His keen, observing mind could not long remain indifferent to the fact that many a poor and unsophisticated immigrant to this country became the victim of exploitation. It was in character that he sought to relieve this among people coming from his native country and that he sought to do it through normal and realistic channels, and so he made himself responsible for the organization of the Bank of Naples Trust Company of New York, of which he is now president, director, and chairman of the board.

During the World War he acted as consultant to the Navy Department in the design of electric cables on shipboard.

His sense of responsibility to the community appears again in his service for several years as a trustee of his home town of Bronxville, culminating in a term of service as mayor of the town.

I probably have made a poor presentation of the ways in which the industry has benefited from Torchio's life, but I am sure you will all agree that he is a most worthy exponent of the meritorious achievement for which the Edison Medal was founded.

It is partially because he has been my teacher and my guide for 25 years that I consider it a great honor and privilege to be allowed to present Philip Torchio on behalf of the Edison Medal committee.

An Engineer in the Power Industry

PHILIP TORCHIO, Fellow AIEE

When I first went to the New York Edison Company in 1895, I became very much interested in the study of all factors that influence the cost of production. As an illustration of such interest I have, among my papers, a duration curve entitled "Curve Showing Number of Hours During Which the Load on Duane Street Station Did Not Exceed a Given Percentage of the Annual Maximum Load—Year 1895." In a marginal tabulation are given, in percentages of the annual maximum, the hours' use of the station under different loads. The load was greater than 70 per cent of the maximum for less than 1 per cent of the time. For nearly 50 per cent of the time the load did not exceed $6^1/_2$ per cent of the maximum. Accompanying the curve follows a report of three weeks' tests to determine the cost of operation for different watches, and the remark is made that by increasing by 50 per cent the output of the minimum watches, the increased output could be produced at one-fifth of the average pounds of coal per kilowatt-hour consumed during the minimum-load watch. I do not believe that a duration curve of the operation of a central station had ever been assembled before. From the broad economic point of view its importance is just as great today as it was in 1895. Upon its underlying principles has been built the structure of efficient operation of plant, economic utilization of investments, and promotional rate schedules.

In a lighter vein, while engaged in these efficiency tests, I made by the Orsat method a Btu test of some samples of different coals, but when I submitted them to the purchasing agent I was discouraged from pursuing such investigation, because, he said, the heating power stored in the coal millions of years ago would not be changed by any amount of testing.

With the steady growth of demand for increased services developed the desirability of determining the most economical cross section of copper wires used in our distributing mains and feeders. The subject necessitated extensive studies which were made available in 1900 to the Association of Edison Companies. As a side line an interesting analysis, published in the 1901 AIEE TRANSACTIONS, gave the large savings in investments that could be made by using double voltage lamps, as was then the general practice, and still is, in England, and later in some other countries. Unfortunately, with carbon filaments, then in use, the double voltage lamps required, for same life, considerably greater wattage per candle power, which would have offset most of the savings in plant investment. With metallic-filament lamps such a drawback is no longer present, but the cost of a change is now prohibitive. We miss the advantages of higher distribution voltages enjoyed in other countries whenever devices of heavy power consumption, as for instance electric ranges and space heaters, are to be connected.

While pursuing these practical studies of economics in transmission of electricity in 1901, I was impressed by the lively electrical charge shown by the rubber-insulated braided cables used to wire the different compartments of the high-voltage switchboards. It seemed to me that this process of charging insulation also might possibly involve some loss of power. Accordingly we arranged to measure the suspected losses on two three-phase feeders, one insulated with rubber and one with paper. These were the first measurements of dielectric losses, which in later years became the bases of reference for studying all improvements in the art of cable manufacture and operation.

Incidentally, this investigation, and the related study of the laws that govern the distribution of potential in a medium made up of different strata each having different inductive capacities, have been of great help in many directions, but most effectively in the analysis of high-voltage system disturbances and insulation breakdowns. Of these you will find a graphic illustration in the 1913 TRANSACTIONS—a set of photographs showing step by step the deterioration of the rubber insulation in a cable under test, and the final breakdown. A few years ago I asked a friend to make a moving picture of the photographs but he could not succeed in getting satisfactory results.

Speaking of pictures, the oscillograph has been a godsend

to the electrical industry. To study the sources of the apparently enormous currents in high-voltage disturbances, in 1909 short-circuit oscillograph tests were made, in co-operation with the manufacturer, on one of our large turbine units. The results indicated the desirability of providing means of reducing the amount of generator short-circuit currents. In a certain manner the development of a system of devices that would automatically keep the current within the safe limits of each particular circuit appealed to me as vital to the maintenance of continuity of service on the system. This policy of continuity of service had developed under the inspiration of the early Edison pride in keeping the service going under all possible difficulties, of which policy John W. Lieb, one of the early Edison Medalists, was the highest exponent in our company. It was therefore natural that the company should be one of the leaders in the design and use of reactance coils for the protection of its high-voltage services.

Following the urge for a close knowledge of the fundamentals of the industry, throughout the early period of my association with the company I made it a point of duty to inspect and closely analyze the circumstances of all breakdowns on the high-voltage system. The information so obtained was of inestimable value in suggesting improvements on the system in all its ramifications. Some of these studies assumed great importance in enabling us to point out to manufacturers ways of making considerable improvements in high-voltage circuit breakers, large turbogenerators, and high-voltage cables.

Of equally inestimable value have been the studies of engineering economics in aiding the company toward a combined technical and commercial progress.

In the larger field of national power economics the subject is so broad that one is apt to become stalled in the study of a phase of the problem and lose the perspective of the whole. I was attracted to this subject during the last war when the problem of power and coal supply to the nation became the subject of concern to the government. For my personal information I made an extensive study which was later reproduced in the 1920 TRANSACTIONS. One of the astonishing results therein given is that, for 1915, if the nation had used all the potential hydro power which is available east of the Rockies it would have supplied only eight per cent of the total energy for all its heating and power requirements. Many times the equivalent of that total amount of hydro energy could be secured by changing the existing inefficient methods of utilizing the fuels, provided the cost of the changes would not stand in the way.

In concluding, what I wish to convey is that my close and intimate association with the growth of the industry, and the constant love for its better knowledge, have been the mainsprings of what you may consider a possible contribution to its development. Such results could not have been accomplished without the progressive policies of the company and the invaluable co-operation of the men associated with me in the work. Looking forward I firmly believe that the power industry is still in the stage of youthful expansion, and holds out its glowing promise to all young engineers of good will.

Engineers as Arbitrators

Engineers are urged to apply themselves constructively to the problem of adjudication of disputes between management and labor

IF WE HAD no other index of the importance of labor in the economic life of the United States than the extent to which the newspapers daily deal with the subject, we would still be right in concluding that the problems associated with labor relations in industry are of grave significance and warrant the most earnest consideration by the constructively minded and thinking people of the nation. Since, however, the labor question is deeply involved in those processes with which engineers as a class are closely associated, any observations emphasizing the importance of labor in industry to them should not be necessary. I can think of no professional class in society that really comes into closer contact with labor problems at the source than do the engineers. It seems to me very appropriate, therefore, for our engineers to tarry occasionally in the pursuit of their careers and determine for themselves whether they might not be missing an opportunity to make a constructive contribution to the more orderly solution of the human problems incident to the conduct of industry and, if so, what the nature of that contribution might be.

I shall sketch very briefly the situation which, as I see it, opens the door for the qualified engineer to play his part in the more orderly development of labor relations, and second, give some idea, gleaned from my experience and observations, as to what an engineer is up against who might aspire to help adjust or sit in judgment of specific issues growing out of the labor problem.

The basic objective of many declarations of public

Excerpts from an address of the same title delivered by Otto S. Beyer, chairman, National Mediation Board, at the 20th annual assembly of American Engineering Council, Washington, D. C., January 12, 1940.

policy and related federal and state laws, such, for example, as the Norris-La Guardia Anti-Injunction Act, the National Labor Relations Act, the Railway Labor Act, and Title X of the Merchant Marine Act, is to further the process of collective bargaining in industry as a means toward establishing the so-called labor standards of industry, that is, the rates of pay, hours, and working conditions of labor.

Collective bargaining has come to mean: first, the organization of employees into so-called labor unions of their own choosing; second, the acceptance by management of these unions as speaking for the employees in all matters of vital concern to them; third, the negotiation particularly of labor agreements between management and these unions defining rates of pay, hours, rules, and working conditions; and fourth, the provision of methods for assuring that the terms of such labor agreements are effectively observed.

Where proper advantage is taken of the opportunities provided by law and otherwise to negotiate labor agreements under the auspices of collective bargaining, three processes are utilized, either separately or in serial combination, to achieve the objectives sought. The first process is that of direct negotiation between representatives of management and of employees. The second process is that of mediation, and the third, arbitration.

Thus, where collective bargaining is employed for the purposes of establishing the labor standards of industry, the services of four types of individuals may be utilized in connection with one or another phase of the process. The first type is the negotiator. He may represent either the employer or the employees. In either case, he must be experienced and competent, and certainly he must know a great deal about the game in which he is required to play so important a part. The second type is that of the mediator, sometimes called conciliator. He, too, should have an intelligent grasp of the problems of industry and labor, be able to talk the language of the representatives to a given labor negotiation, and be endowed with the faculty of inspiring confidence as an intermediary. The third and fourth types, namely, arbitrators and referees or impartial chairmen, must be essentially judicial in their approach to the matters in respect of which they are called upon to sit in judgment. Here again, an adequate background of the processes and economics of industry, together with a faculty to analyze testimony and weigh arguments, is important in persons selected for such assignments.

Except for the first type of individual, namely, the negotiators serving as the direct representatives of the parties immediately concerned in the making of labor agreements, the other three types, in addition to expert knowledge and comprehension of the problems of labor and industry, must be strictly impartial as between the interests involved in the proceedings. That the engineer is equipped by education, training, and experience to serve industry on the technical side superficially argues that he also ought to be able effectively to appraise and understand the economic and human phases of the industrial process. In all events, the engineer is exposed to these sides day by day no less than he is exposed to the technical side of industry, and so, if sufficiently curious and imaginative, ought to generate as healthy an understanding and appreciation of these other sides as he has of the technical problems of his profession. The situation, however, as regards the engineer is not so simple as this.

The labor problem is essentially a problem of the distribution of the proceeds of industry. The worker, under our present economic system, receives his share of the wealth created by production chiefly through his pay envelope. The significance of this fact has never been more clearly presented than by the so-called Lane Commission in its report to the Director General of Railroads, dated April 30, 1918, in which it observed:

> "To ask a man, 'What wages should you in justice receive?' is to ask perhaps the profoundest of all human questions. He is at once compelled to an appraisement of his own contribution to the general good. He must look not selfishly on his own material needs, but take a far view of the needs of those dependent upon him. He must go into the whole involved problem of his relationship with his fellows, and to answer the question aright he must in the end come to a judgment which will be nothing less than a determination of what policy or plan of wage adjustment will make for the permanent well-being of the State."

Concrete questions, difficulties, disputes, and the like in the field of labor relations are all variants, in one form or another, of the basic issue posed in the foregoing observations of the Lane Commission. The reference of issues arising between labor and management either to mediators, arbitrators, or referees for their orderly adjudication is very recent in society. Ordinary difficulties and problems arising between men in society have been adjudicated for thousands of years by courts of law and justice, and a whole body of practical and expert personnel in the form of lawyers and judges has come into being to deal with these matters. There have been no corresponding developments as yet, however, either as far as laws or as far as personnel and agencies are concerned, working to settle the so-called labor problems of society in the same orderly ways that have been devised to settle other types of differences between men in society. Yet the situations out of which labor problems and related difficulties grow are more fundamental to society than many of the usual legal questions presented to our courts for adjudication.

Rapid progress, however, is being made in formulating more scientific and orderly methods for dealing with the labor problems of industry. In so far as the engineering profession can see its way clear to take cognizance of this phenomenon and realize that engineers as a class might well prove a fertile field for recruiting a body of competent, intelligent individuals to serve industry and labor in a neutral capacity in the adjudication of their conflicts, the profession would greatly increase its usefulness to society. What it takes to bring this about is another subject well worthy of very serious consideration, and I trust the engineers will apply themselves constructively to this problem. If they do and make available to us who are continuously on the lookout for broadminded, intelligent, socially conscious, and technically well-informed and equipped individuals, it will be possible to provide them with ample opportunity to employ their talents.

Electric Distribution Systems in Buildings

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Increased intensity of illumination and the upward trend in industrial power requirements have loaded the electric distribution systems in many buildings beyond their rated capacities, requiring many extensive rewiring jobs that could have been avoided by the provision of adequate reserve capacity in the original installation. It is pointed out here that even though no material increase in load results after a number of years, a system having more than the capacity required by code rules is economical.

DESIGN of distribution systems within buildings has generally been based upon the National Electrical Code requirements for conductor capacities, with various allowances for voltage losses. Excess capacity, for future increases in load, has been limited to buildings where some future expansion is contemplated or expected at the time the system is installed. Where no increase in load is expected, the first cost is the principal factor that controls the design and prevents excess capacity from being installed. Little, if any, consideration is given to the cost of energy losses. Economy of operation is based upon the sum of capital costs and energy losses. Several of the factors affecting these costs are considered herein, principally system characteristics, voltage regulation, and conductor capacity.

System Characteristics

Of the many variables affecting the cost of distribution systems, the system characteristics can be considered only where the utility service to a building is at primary voltage and where there is a choice of several systems, such as single phase, three wire; two phase, five wire; three phase, three wire; or three phase, four wire for lighting; and two phase, four wire; or three phase, three wire for power.

An approximation of the relative costs of these various systems is shown in table I. These figures are for the conduit, wire, and control switches for feeders, and are based upon equal losses and voltage regulation and unity power factor. They indicate that the three-phase four-wire system for lighting and the three-phase three-wire system for power cost less than single-phase or two-phase systems. However, transformer installations for three-phase distribution systems will be found to cost more than for two-phase systems, so that for a complete system there will be less difference in cost than these figures indicate.

Voltage Regulation

In order to determine the voltage regulation requirements for distribution systems the effect of variations in voltage on the different types of loads must be considered.

The characteristics of Mazda incandescent lamps are such that it is desirable to keep the voltage near the rating of the lamp. The lumen output varies approximately as the cube of the voltage, whereas the life varies inversely as the 13th power of the voltage; consequently as the voltage is lowered the life becomes materially longer and the light output is decreased, and vice versa.

A ten-per cent difference in intensity of illumination is just noticeable when it is caused by a sudden fluctuation in voltage, such as results from materially increasing or decreasing the load on a circuit. Larger variations in intensity are much more noticeable and often annoying. A reduction of ten per cent in intensity, however, does not noticeably affect visibility or adequacy of illumination. It would appear that a ten-per cent variation in light output is a reasonable value to use for the determination of voltage regulation. This variation of light from Mazda "C" lamps results from about a three-per cent variation in voltage.

If the cost of operation per unit of light received, that is, energy and lamp renewals divided by lumens output, is plotted against voltage it will be found that the minimum cost is near rated voltage. This is illustrated in figure 1 on the basis of 100- to 500-watt lamps and two cents per kilowatt-hour for energy, in which case the cost for light is minimum at approximately 105 per cent of the rated voltage of the lamp. Obviously, the cost of energy determines the point at which the lowest cost for light is obtained, but near this point within about two per cent difference in voltage above or below it there is little difference in cost. In order to keep within this area, the regulation therefore should be not greater than four per cent.

Induction motors do not require such close voltage regu-

Table I. Approximate Relative Costs of Various Distribution Systems

Unity Power Factor, Equal Losses, and Equal Voltage Regulation

Single phase, three wire, 230/115 volts	1.00
Two phase, five wire, 230/115 volts	0.95
Three phase, four wire, 200/115 volts	0.90
Three phase, three wire, 115 volts	1.75
Two phase, four wire, 230 volts	0.80
Three phase, three wire, 230 volts	0.65
Two phase, four wire, 460 volts	0.45
Three phase, three wire, 460 volts	0.40

A local Section prize paper presented at a meeting of the AIEE Philadelphia Section, May 8, 1930.

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lation. Recommendations of the National Electrical Manufacturers Association permit ten-per cent variation above or below rated voltage so far as temperature conditions are concerned. There are, of course, variations in torque and slip which may become important factors in certain applications. Where the service voltage is 230 volts, approximately five-per cent line drop will produce rated voltage at 220-volt motor terminals. If the service voltage is 208 volts, five-per cent drop is obviously the maximum permissible where 220-volt motors are used. In the great majority of installations, however, the distance from the service point to the motors is not so great as to cause the drop to exceed five per cent at full load, if the requirements of the National Electrical Code are followed in determining conductor sizes. Furthermore, the demand for the majority of motor loads is of the order of half the connected load. The proper operating conditions in such instances can be obtained without consideration of voltage regulation.

Distribution Economics

The effect of voltage regulation and conductor capacity on annual operating costs is indicated in figures 2 and 3. Figure 2 shows how the energy losses and capital charges for a lighting distribution system vary with different values of voltage regulation. Obviously, the cost of energy, lengths of circuits, average demand in relation to connected load, and hours of use are all variables that enter into the picture. These curves are intended to represent an average condition and show that there is a low point for the total operating cost between two- and four-per cent voltage regulation. Unless circuit lengths are very short, two-per cent regulation appears to be the minimum desirable from the standpoint of total operating costs. These figures, it should be noted, are for the complete distribution system including branches and feeders, and are based upon connected loads, so far as calculation of the voltage drop is concerned, but upon 70 per cent of the connected load for determination of losses.

For induction-motor loads the voltage regulation will not vary in proportion to the losses, because of the effect of power factor and line reactance, so a different basis of comparison is necessary. The costs in figure 3, therefore, are plotted against the capacity of the conductors, based upon the 1937 National Electrical Code. These curves

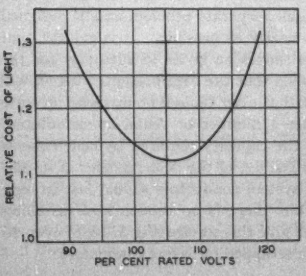


Figure 1. Variation with voltage of cost of lamp renewals and energy, per unit of light, cost of energy assumed to be two cents per kilowatt-hour

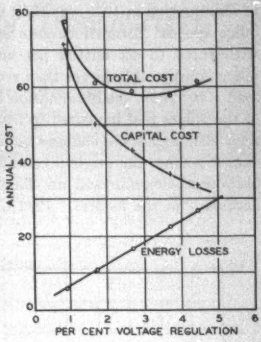


Figure 2. Variation of annual cost with voltage regulation for a complete lighting distribution system (feeders and branch circuits)

Voltage regulation based upon connected load. Energy losses based upon 70 per cent of connected load for 2,000 hours per year at two cents per kilowatt-hour. Capital cost includes: interest 3.5 per cent; depreciation 2 per cent; taxes and insurance 1.5 per cent

are, of course, subject to the variables mentioned in the preceding paragraph, but, for the values used, show the sum of carrying charges and energy losses to be at a minimum when the capacity of the conductor is about 20 per cent greater than the connected load requires. In fact, to increase the size to 40 per cent more than the minimum size would not increase the operating costs above that obtained with the minimum size.

Adequacy

This is the point that should be emphasized, namely, that conductors may be installed for larger than the connected load, thus providing for unforeseen increases in load, without increasing the total cost of operation. As has happened so often with buildings wired for minimum first cost, if an increase in load is made five or ten years later, the provision of sufficient capacity in the distribution system becomes an expense that could have been avoided.

The case of an adequate original installation is illustrated by the lighting distribution system for a bank- and office-building in Philadelphia, Pa. The original intensity

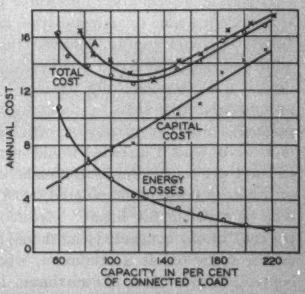


Figure 3. Variation of annual cost of a feeder with capacity, based upon National Electrical Code ratings for connected load

Energy losses based upon 50 per cent of connected load for 2,000 hours per year at two cents per kilowatt-hour. Capital costs same as in figure 2

Curve *A* indicates the total cost if heat-resisting insulation and capacities as specified by the National Electrical Manufacturers Association are used

of illumination in 1928 was eight to ten foot-candles in the office spaces. Branch circuits were of number 12 wire with three to six outlets per circuit, and feeders were made considerably larger than required by the connected load. By 1939, the illumination intensities in 70 per cent of the offices had increased to from 15 to 20 foot-candles, and, although some changes have been made in branch-circuit wiring, the original conduit installation never has become inadequate and no change whatsoever has been necessary in the feeders. Part of the feeder runs, being

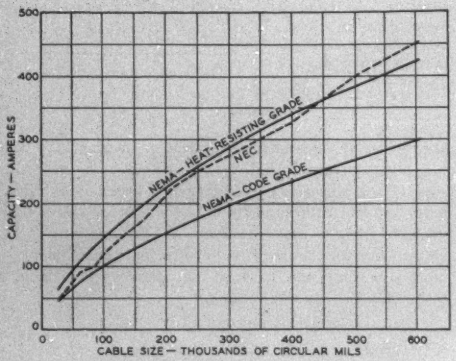


Figure 4. Current ratings for three wires in conduit, as specified by National Electrical Code and National Electrical Manufacturers Association

concealed, cannot be changed without considerable cutting and consequent repairs to the building, yet they are large enough for even greater increases in load. The opposite case is illustrated by several instances of office lighting where the cost of the changes required in order to provide increased capacity for greater intensities of illumination was equal to, or more than, the cost of installing new fixtures.

It is difficult and often impossible to estimate the load that may be added to an installation in any great period of time. It would appear, however, that for lighting loads additional capacity equal to 50 per cent of the connected load may be economically justified. This would be approximately equivalent to designing the system for two-per cent voltage regulation, in which case the 50-per cent increase in load if installed would increase the regulation to three per cent. For motor loads, the type of building or industry must be considered, with the additions that may be made in the future. An allowance of 25 to 50 per cent of the connected load should be found economical and is suggested as a minimum, where no additions are contemplated. Since the maximum load or demand for power purposes is usually well below the connected load, conductors 50 per cent larger than required by the connected load ordinarily will provide for a 100- to 200-per cent increase in demand.

Conductor Capacities

In connection with the provision of adequate capacity, consideration must be given to the report of the subcommittee on determination of maximum permissible current-carrying capacity of code-insulated wires and cables of the National Electrical Manufacturers Association. Figure 4 shows graphically the capacities of number 6 (American Wire Gauge) and larger rubber-insulated wires as given by the 1937 National Electrical Code and as determined by the NEMA investigations for three wires in conduit. In the sizes from number 14 to number 8 the NEC ratings are about equal to those given by NEMA for code-grade insulation, but for number 6 and larger the NEMA rating is lower and the difference becomes proportionately greater as the size is increased. For heat-resisting grade, however, the NEMA ratings are slightly better than NEC ratings, up to 400,000 circular mils.

In table II a comparison of the cost of conduit and wire installed for both code and heat-resisting grades is given with the capacity of each, based on the NEMA table for three-wire systems. This clearly indicates that heat-resisting rubber insulation is to be preferred to a larger size of code grade to obtain the required capacity.

Table II. Comparison of Costs of Conduit and Wire, Installed—Code Grade and Heat-Resisting Grade

Grade	Conductor Size	Amperes Capacity, NEMA	Approximate Cost per 100 Feet Installed, Three Wires in Conduit
Code	1/0	105	$101
Heat resisting	2	115	80
Code	4/0	160	146
Heat resisting	2/0	173	112
Code	400,000 cir mils	233	215
Heat resisting	4/0	230	153

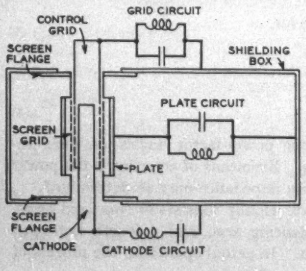
The NEMA ratings for heat-resisting grade differ only slightly from the NEC ratings in the larger sizes, and the difference in cost between code grade and heat-resisting grade is of the order of five per cent of the total cost of the conduit and wire installation; thus the use of heat-resisting insulation and NEMA ratings will not materially affect the curves of figures 2 and 3. This is illustrated in figure 3 by curve *A*.

With the many variables to be considered in the design of distribution systems within buildings, each installation must be considered as a separate problem and be designed to fit the needs as nearly as possible. It is evident that more consideration should be given to adequacy for the future, and it is hoped that the data presented herein will illustrate the point that even though no material increase in load results after a number of years, an installation having more than the capacity required by code rules is economical. With the use of the better grades of insulation, the electrical-system conductors should last as long as the building; but there is no economy in installing conductors that will give this service if in 5, 10, or even 15 years they are to be scrapped for larger conductors.

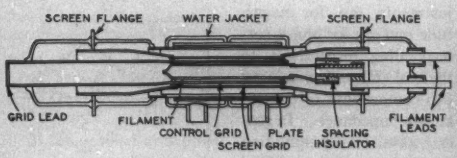
A 20-Kw Tetrode for Ultrahigh-Frequency Transmitters

THE advent of television emphasized the need for a power-amplifier tube capable of delivering kilowatts of power into wide-band circuits at carrier frequencies above 40 megacycles. To obtain such output with wide-band circuits, a low output capacitance and consequently a small anode area are required. The result is high current and high dissipation per unit area. For satisfactory operation at high frequencies, the electron transit time must be small, necessitating small interelectrode spacings. These requirements are interrelated and in some measure conflicting.

On the basis of an analysis of the foregoing considerations, and to meet specific requirements, a tube was designed to deliver 20 kw peak power at 120 megacycles into a circuit of 2 megacycles band width. The design and construction of this tube and test results obtained were discussed in a three-part paper entitled "Development of a 20-Kw Tetrode for Ultrahigh-Frequency Transmitters," by A. V. Haeff (A'31), L. S. Nergaard, W. G. Wagener, P. D. Zottu, R. B. Ayer, and H. E. Gihring, presented at the annual convention of the Institute of Radio Engineers, New York, N. Y., September 20–23, 1939.



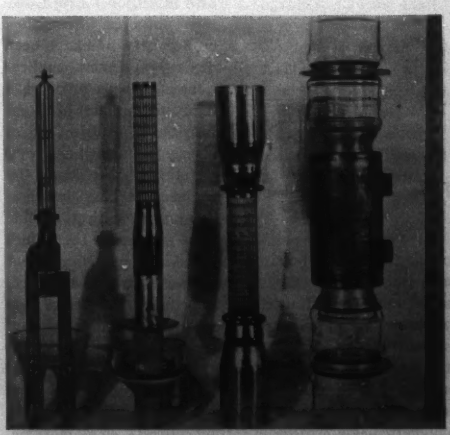
Schematic diagram of the tube and its associated circuit. A cross section of completed tube is shown below



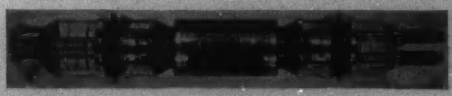
To avoid neutralization difficulties, the cylindrical tetrode design was adopted. Once this design had been decided upon, it was necessary to consider the tube in relation to its circuit in order that the full advantages of the screen grid might be realized. This was particularly necessary because the carrier frequency is high enough so that the tube and its circuit tend to merge into a composite unity rather than remain distinct elements. After this problem had been examined in detail and model tests had been made, the arrangement shown schematically in the accompanying diagram was adopted. The screen-grid is mounted on radial flanges. These flanges are connected to the shield which encloses the output circuit. As may be noted, the cathode and control grid are brought out at opposite ends of the tube, which permits independent tuning of the grid and cathode circuits and makes the tube well suited to operation in a push-pull circuit.

The mechanical design and construction of the tube to meet the electrical requirements involved problems not usually encountered in power tubes. The high power and high frequency made the elimination of insulating members in the active region imperative. Consequently, the electrodes were supported by the glass work at each end of the tube. The severe thermal conditions required water-cooling of the anode, the control-grid support, and the filament leads.

Tests show that the tube is capable of being operated stably at all frequencies up to 80 megacycles or higher and delivering power outputs as high as 25 to 28 kw per tube at an efficiency of about 55 per cent. It has a peak plate current of at least 25 amperes which is sufficient to furnish 20 kw per tube when operating as a television radio-frequency amplifier with a calculated band width of 9 megacycles.



Component parts of the tube, left to right: filament structure, control grid, screen grid, and anode assembly with integral water jacket. Below is shown the completed tube; it is $30^1/_2$ inches long and $5^1/_2$ inches in diameter



A Brief Summary of Bridge Networks

WALTER J. SEELEY
MEMBER AIEE

An outline classification of bridge networks that may be of assistance to users of bridges, students, and others interested in the subject

THE BRIDGE CIRCUIT, which was first introduced in 1833 by S. H. Christie, is one of the most useful electric circuits ever devised. It is so versatile that one could obtain a very liberal training in electric circuits if study were confined to it alone. Sir Charles Wheatstone, in 1843, made the first real application of the network when he applied it to the comparison of resistances. From that time his name has been attached to the use of the bridge for d-c determinations of resistance. Heaviside tried to call it the Christie, but the name did not seem to stick. Maxwell, in 1865, was the first to attempt the determination of inductance in a bridge circuit, using a ballistic method; later, in 1873, he described several forms of balances or bridges. His bridges form the basis of many modern impedance bridges.

The modern a-c bridge is due to the developments of Max Wien, who first applied alternating current to Maxwell's bridges in 1891. He also proposed networks of his own invention for measurement purposes. From then on new networks have been devised and new applications have been made until today the amount of literature on the subject is so utterly amazing as completely to bewilder the engineer seeking information on the subject. Aside from measuring the values of the fundamental constants, resistance, inductance, and capacitance, with their related constants, conductance, susceptance, admittance, and impedance, the bridge network has been applied to the determination of frequency, speed, time, power, power factor, electromagnetic forces, the soundness of welds, and acoustic impedance. It is also used to measure deflection of beams, torsion of large shafts, shaft horsepower, pressures in engine cylinders, magnetic fields, stresses in setting concrete, small motions, vacua, and many other things.

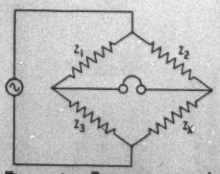


Figure 1. Four-arm impedance bridge

The purpose of this article is to present a brief classification of bridge networks (mutual-inductance bridges not included) according to name, giving balance equations for each. Theory, operation, and application of the various types are referred to in a selected bibliography. The development and classification for the most part is a brief review of the one first proposed by J. G. Ferguson.[1] Others have been proposed, but for the purpose of this article Ferguson's classification seems to be the one most logical to follow.

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1. For numbered references see bibliography at end of article.

General Theory

At balance, the products of opposite arms of a four-arm bridge are equal, all impedances being expressed in complex notation for final evaluation of the unknown. The balance conditions are then obtained by equating reals and imaginaries. Thus, at balance from figure 1,

$$Z_1 Z_x = Z_2 Z_3 \tag{1}$$

from which

$$R_x + jX_x = \frac{(R_3 + jX_3)(R_4 + jX_4)}{R_1 + jX_1} \tag{2}$$

In terms of magnitudes,

$$|Z_1||Z_x| = |Z_2||Z_3|$$

and

$$\theta_1 + \theta_x = \theta_2 + \theta_3 \tag{3}$$

where the θ's are the power-factor angles of their respective impedances. By means of equation 3 the power factor of the unknown impedance may be determined.

The bridge network usually consists of two fixed arms, a third variable balancing arm, and a fourth arm containing the unknown. In actual operation, the process of balancing requires two adjustments, one for magnitude and one for phase, corresponding respectively to the real (R) and imaginary (X) components of the unknown impedance. In general, for ease in manipulation the real component (R) of the impedance in the third, or variable, arm should balance the real component (R) of the unknown; and

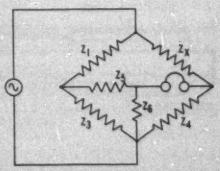


Figure 2. Anderson bridge

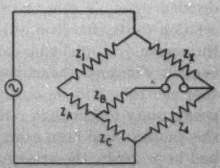


Figure 3. Anderson bridge with impedances Z_3, Z_5, and Z_6 (figure 2) transformed into equivalent star network

the imaginary component (X) of the impedance of the third arm should balance the imaginary component (X) of the unknown.

If, in figure 1, the arms Z_1 and Z_2 are the fixed arms and Z_3 the variable balancing arm, the bridge is known as a ratio-arm bridge, with Z_1 and Z_2 the ratio arms; if Z_2 and Z_3 are the fixed arms and Z_1 the variable balancing arm, the bridge is known as a product-arm bridge, with Z_2 and Z_3 the product arms. For the ratio-arm bridge,

$$Z_x = \frac{Z_2}{Z_1} \cdot Z_3 \tag{4}$$

and for the product-arm bridge,

$$Z_x = Z_2 Z_3 \cdot \frac{1}{Z_1} \tag{5}$$

This classification of bridges into ratio-arm and product-arm types may seem to be somewhat artificial, as it is sometimes difficult to decide into just which type a particular bridge should be classified. It is a fairly simple classification, however, has been extensively analyzed,[1] and is subject to but few exceptions.

In the ratio-arm bridge the unknown is balanced by a series impedance, Z_3, in an adjacent arm, and the vector ratio Z_2/Z_1 must be real or imaginary (but not complex) with the difference between their phase angles ($\theta_2 - \theta_1$) equal to 0, 180, or ± 90 degrees. Solving equation 4 for the case where Z_2/Z_1 is real ($\theta_2 - \theta_1 = 0$ or 180 degrees),

$$R_x + jX_x = \frac{Z_2}{Z_1}(R_3 + jX_3) \tag{6}$$

from which, upon equating reals and imaginaries,

$$R_x = \frac{Z_2}{Z_1} R_3 = \frac{R_2}{R_1} R_3 = \frac{X_2}{X_1} R_3 \tag{7}$$

and

$$X_x = \frac{Z_2}{Z_1} X_3 = \frac{R_2}{R_1} X_3 = \frac{X_2}{X_1} X_3 \tag{8}$$

When Z_2/Z_1 is imaginary ($\theta_2 - \theta_1 = \pm 90$ degrees), equation 6 yields

$$R_x = \frac{Z_2}{Z_1} X_3 = -\frac{X_2}{R_1} X_3 = \frac{R_2}{X_1} X_3 \tag{9}$$

and

$$X_x = \frac{Z_2}{Z_1} X_3 = \frac{X_2}{R_1} R_3 = -\frac{R_2}{X_1} R_3 \tag{10}$$

In the product-arm bridge the unknown is balanced by a series or parallel impedance, Z_1 (usually a capacitance and resistance in parallel) in an opposite arm, and the vector product $Z_2 Z_3$ must be real or imaginary (but not complex) with the sum of the phase angles ($\theta_2 + \theta_3$) equal

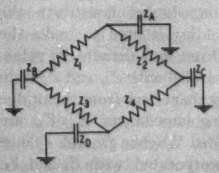


Figure 4. Unshielded impedance bridge showing shunt capacitances to ground

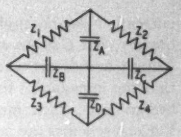


Figure 5. Shielded impedance bridge; stray impedances interconnected with main bridge arms

to 0, 180, or ± 90 degrees. When $Z_2 Z_3$ is real ($\theta_2 + \theta_3 =$ 0 or 180°), equation 5 gives

$$R_x + jX_x = Z_2 Z_3 \cdot \frac{1}{Z_1} = Z_2 Z_3 Y_1 = Z_2 Z_3 (G_1 - jB_1) \tag{11}$$

from which, upon equating reals and imaginaries,

$$R_x = Z_2 Z_3 G_1 = R_2 R_3 G_1 = -X_2 X_3 G_1 \tag{12}$$

and

$$X_x = Z_2 Z_3 (-B_1) = -R_2 R_3 B_1 = X_2 X_3 B_1 \tag{13}$$

When $Z_2 Z_3$ is imaginary ($\theta_2 + \theta_3 = \pm 90$ degrees), equation 11 yields

$$R_x = X_2 R_3 B_1 = X_2 R_3 B_1 \tag{14}$$

and

$$X_x = X_2 R_3 G_1 = X_2 R_3 G_1 \tag{15}$$

Two exceptions to the foregoing rules for ratio-arm and product-arm bridges should be noted. In one use of the Wien bridge[38] a small capacitor, C_2 (not shown in figure 10) is used in parallel with R_2, making Z_2/Z_1 complex with $\theta_2 - \theta_1$ not equal to 0, 180, or ± 90 degrees. In the generalized Schering bridge[45] with a capacitor, C_3 (not shown in figure 15) in parallel with R_3, the product $Z_2 Z_3$ is complex with $\theta_2 + \theta_3$ not equal to 0, 180, or ± 90 degrees. In both these particular cases the bridge relations are determinable, and the bridges can be balanced. See the references for details.

Bridges of the Anderson type (figure 2) may be solved for balance by transforming the $Z_2 Z_3 Z_4$ mesh to its equivalent star network by means of the transformation equations:

$$Z_A = \frac{Z_3 Z_4}{Z_3 + Z_4 + Z_5}, \quad Z_B = \frac{Z_4 Z_5}{Z_3 + Z_4 + Z_5}, \quad Z_C = \frac{Z_3 Z_5}{Z_3 + Z_4 + Z_5} \tag{16}$$

This results in a four-arm bridge (figure 3) for which the equation of balance is

$$Z_2 Z_C = Z_1 (Z_1 + Z_A) \tag{17}$$

and

$$Z_x = \frac{Z_4}{Z_2 Z_5} [Z_1 (Z_3 + Z_4 + Z_5) + Z_3 Z_4] \tag{18}$$

The Wagner Ground

When high frequencies or high potentials are used precise bridge balances are difficult to obtain on account of stray impedances and the impedances to ground of the various bridge arms. These impedances are usually capacitive in nature and variable in value depending upon the relation between the arms and surrounding objects. Although the capacitances may be small, the current through them may be large since $I = V\omega C$, where I is the

current, V is the applied voltage, ω is 2π times the frequency, and C is the capacitance. The bridge of figure 4 (supply and detector circuits omitted for simplicity) shows that the impedances to ground, Z_A, Z_B, Z_C, Z_D, shunt the bridge arms thus making precise balances impossible. Various schemes are used to eliminate the effects of these impedances to ground, namely, double shielding, the Wagner ground, and combinations of shielding and the Wagner ground.

The chief purpose of shielding is to make the ground impedances definite in magnitude, location, and effects. It is possible by very elaborate and well-designed double shielding[11,13] to localize and concentrate the capacitance effects between the diagonal corners of the bridge. This places the capacitance in one case in parallel with the detector and in the other in parallel with the source of supply, thus preventing them from affecting the bridge balance. An adjustment is sometimes provided to take care of any remaining unbalance to ground of the detector circuit. The shielding also may be designed[30] to localize the stray capacitance across one particular arm of the bridge where it is taken care of by proper adjustments in the initial calibration. Figure 5 is the same as figure 4, but redrawn to show the interconnection of the stray impedances with the main bridge arms. The impedances Z_1, Z_2, Z_3, Z_4 constitute the ordinary bridge arms, and Z_A, Z_B, Z_C, Z_D, represent the impedances of the four corners to ground or to a shield. It has been shown[7,11,47] that the ordinary bridge relation, $Z_1Z_4=Z_2Z_3$, holds if

$$Z_A/Z_D=Z_3/Z_4=Z_1/Z_2 \qquad (19)$$

or

$$Z_B/Z_C=Z_3/Z_4=Z_1/Z_2 \qquad (20)$$

These equations mean that, by properly balancing the shields during manufacture and providing a shield adjustment, the bridge balance may be made independent of any stray or extraneous coupling impedances.

Another scheme used to nullify the effects of stray and distributed capacitances is to make use of partial shielding and the Wagner ground. The bridge construction is simpler, but additional operations are required in the balancing process. Figure 6 shows a bridge (detector circuit omitted) with two additional adjustable impedances, Z_5, Z_6, connected in series across the supply circuit. These last two grounded impedances constitute the Wagner ground. Partial shielding is used to make the stray impedances to ground fixed and definite in value. The impedance Z_B is now in parallel with Z_5, and Z_C is in parallel with Z_6, thus removing them both from the bridge circuit proper. The remaining impedances, Z_A, Z_D, are removed by the use of the added Wagner ground. Since Z_B and Z_C now have been incorporated with Z_5 and Z_6,

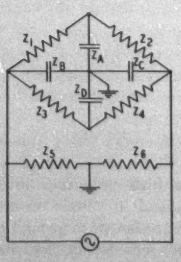


Figure 6. Shielded impedance bridge with Wagner ground

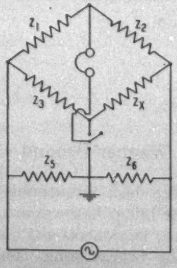


Figure 7. Diagram illustrating the process of balancing with the Wagner ground

Figure 8. Impedance bridge (Maxwell)

$R_1=R_2$; R_3, L_3 variable.
Measures L, R in terms of L, R.
At balance:

$R_x=R_3$ $\qquad L_x=L_3$

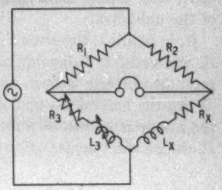


Figure 9. Impedance bridge

$R_1=R_2$; R_3, C_3 variable.
Measures C, R in terms of C, R.
At balance:

$R_x=R_3$ $\qquad C_x=C_3$

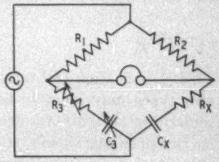


Figure 10. Wien bridge

$R_1=R_2$; R_3, C_3 variable.
Measures C and parallel R in terms of C, R, and f.
At balance:

$$C_x=\frac{R_1}{R_3}\cdot\frac{C_3}{1+\omega^2C_3^2R_3^2}$$

$$R_x=\frac{R_3}{R_1}\cdot\frac{1+\omega^2C_3^2R_3^2}{\omega^2C_3^2R_3}$$

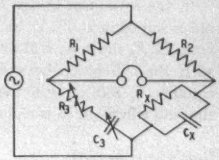


Figure 11. Owen bridge

Difference between phase angles of ratio arms is ± 90 degrees.
Measures L in terms of C and R.
At balance:

$$R_x=R_3\frac{C_1}{C_3}-R_4; \qquad L_x=R_3R_3C_1$$

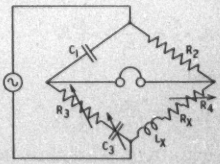
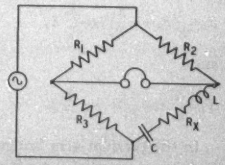


Figure 12. Resonance bridge

Measures L in terms of C and f; C in terms of L and f; or f in terms of L and C.
$R_1=R_2$
At balance:

$R_x=R_3$ $\qquad L=\dfrac{1}{\omega^2C}$



Product-Arm Bridges

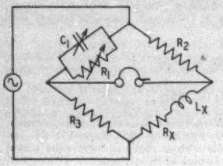


Figure 13. Maxwell bridge

Measures L in terms of R and C.
At balance:

$$R_x = R_2R_3 \cdot \frac{1}{R_1} \qquad L_x = R_2R_3C_1$$

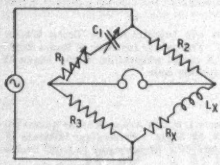


Figure 14. Hay bridge

Measures L in terms of R, C, and f.
At balance:

$$L_x = \frac{R_2R_3C_1}{1+R_1^2\omega^2C_1^2}$$

$$R_x = \frac{R_1R_2R_3\omega^2C_1^2}{1+R_1^2\omega^2C_1^2}$$

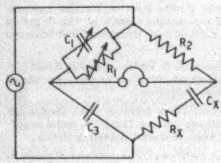


Figure 15. Schering bridge

Measures C and R in terms of C and R.
Sum of phase angles of product arms equals ± 90 degrees.
At balance:

$$R_x = \frac{R_2}{C_3} \cdot C_1 \qquad C_x = \frac{C_3}{R_2} \cdot R_1$$

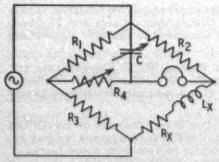


Figure 16. Anderson bridge

Measures L in terms of R and C.
At balance:

$$L_x = CR_2\left[R_4\left(\frac{R_3}{R_1}+1\right)+R_3\right]$$

$$R_x = \frac{R_3R_4}{R_1}$$

the circuit of figure 6 reduces to that of figure 5, for which equation 20 applies. That is, the ordinary bridge relation, $Z_1/Z_2 = Z_3/Z_4$, holds when

$$Z_A/Z_4 = Z_3/Z_4 = Z_1/Z_2 \qquad (21)$$

where Z_3 now includes Z_B, and Z_4 includes Z_C. All that is necessary, therefore, is to balance Z_3 and Z_4 against Z_1 and Z_2 (or Z_3 and Z_4) and all stray impedances (usually capacitances) are removed from the bridge circuit. This is a very convenient and much used circuit. The process of balancing is simple. The bridge is first balanced as nearly as possible with the switch closed in the upper position (see figure 7); then with the switch in the lower position it is rebalanced. The process is repeated until exact balance is obtained; then the relations of equation 21 have been satisfied and the balance equation may be applied to determine the unknown. The arms Z_3 and Z_4 must be of such a nature that they form a balanceable bridge with Z_1 and Z_2. By virtue of its ability to remove undesired capacitances from the influence of the balance relations, the Wagner ground is also frequently used for measurements on three-terminal capacitors, cables, and for other measurements where direct capacitance rather than total capacitance is required.[39] Its chief use, however, is in the measurement of small capacitances and power factors.

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Some Unsolved Problems in Transportation

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A review of some of the unsolved problems facing electrical engineers of the railroad and urban-transportation industries points to the need for a research organization supported by the operating companies, to stimulate technical developments in this field.

THE ABILITY to determine and state what comprises the outstanding problems in any field of activity implies very extensive knowledge of the developments in that field and to state the unsolved problems implies even more than this. When we begin to consider what ought to be done or attempted, the assumption is that there is an accepted standard or goal toward which we are striving. The author knows of no clear and comprehensive statement of the goals or ends of modern transportation. However, competition is making increasingly clear that if public transportation is to survive, the industry must strive toward higher levels of convenience, speed, comfort, efficiency, and attractiveness. Today, the public assumes that safety has been given adequate consideration. This, then, is taken as our major premise—that any development that offers hope for improving these factors, through the effort of electrical engineers, is a proper problem for consideration.

Obviously, an article such as this can only scratch the surface of the potential electrical problems in the transportation field, for, after all, this subject is one that would be more appropriate for a large research or scientific organization. Lacking such an organization, the author has attempted to state some of the problems facing electrical engineers of the transportation industry, particularly those in the railroad and urban transportation field.

Power Distribution to Electric Railways

With the development of superpower networks and relay systems furnishing power of utmost reliability, it is taken for granted today that the great power systems supplying our industrial and domestic power needs will likewise furnish power for the electrification of transit systems. Problems involved in the generation and transmission of this power are beyond the scope of this article. However, vital unsolved problems are involved in the purchase and supply of this power.

The power contract itself, which involves the determination of an equitable method for allocating demand charges is one such problem. A problem of more vital concern is the use of commercial voltages and frequencies for heavy railroad electrifications. The economic advantage of using central-station power for railroad electrification is due chiefly to two factors:

1. The energy component of the power rate is lower because the central station can operate larger and consequently more efficient generating units.

2. The demand component of the power rate is lower due to the diversification of railway, commercial, and domestic loads with resulting high load factor, and because extensive joint use of generating and transmission facilities is possible.

It is obvious that the maximum economic advantage of using central station power is obtainable only if the catenary is operated at commercial voltage and frequency. Ten years' experience with an urban-railway power-distribution system wherein all power is furnished to railway substations over regular commercial high-voltage lines,

Essential substance of AIEE Technical Paper 40-15 presented at the AIEE winter convention, New York, N.Y., January 22–26, 1940; paper to be published in full in the 1940 AIEE Transactions volume.

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has convinced the author that joint use of transmission lines and distribution facilities is dependable and economical, and that with suitable railway and power-system design, such commercial feeders in no respect jeopardize the transportation service.

A review of the existing power distribution facilities of various heavy transportation systems raises the question whether the transportation power-system design has been adequately or fully co-ordinated with the power-supply systems.

Although engineers in the United States seem to be satisfied with a variety of direct-current and 25-cycle distribution systems, several European countries are vigorously experimenting with the use of commercial voltages and frequencies. From the results obtained, it would seem that there are distinct possibilities for the adoption and use of commercial types of power supply for heavy railroad electrifications which should result in reduction of the large investment required for main-line electrification. The solution of the problem involved in making such equipment commercially available offers a challenge to the skill and ingenuity of electrical engineers.

Closely related to this problem of power supply is the problem of constructing a catenary and distribution system at a lower cost than that of systems now available. One of the great difficulties in the electrification of main-line railroads is that the catenary and distribution system must be installed complete over fairly large areas in order to secure economies in operation and it must be installed on the basis of handling the maximum traffic expected within the near future. This requires a heavy investment involving large fixed charges that continue even if the traffic does not come up to expectations. The present trend of main-line motive power to self-contained units is largely due to an effort to avoid these fixed charges. Should a solution be found that would permit a drastic reduction in the cost of catenary and distribution systems, this trend might easily be reversed.

Considering further the various distribution systems of the electrified rail lines of the United States, it is clear that another major unsolved problem in electrical engineering is involved in the standardization of these systems.

When we consider problems of this kind from the standpoint of national defense, they take on an even greater significance. Transportation units must be capable of mobilization in various parts of the country. England, France, and Germany realizing this have adopted national standards.

Standardization of motive power units is not necessary to obtain the essential requirements for mobility, but standardization is desirable in this respect if the railroads are to secure the tremendous economic advantage of mass production.

For the welfare of the electric transportation system as a whole and everyone individually involved in it, standardization is imperative. Major competition today is with transportation units produced by mass-production technic. This is true not only of private cars, but also of motor- and air-transportation units. We need not fear that standardization will impair initiative and new development, because the driving force of competition is present today in the transportation field in greater degree than ever before.

Perhaps if some degree of standardization can be attained, the suggestion contained in the National Power Survey—The Use of Electric Power in Transportation, issued in 1936 by the Federal Power Commission, for an increased electrification mileage of 12,000 miles of track on 20 steam railroads, involving an annual energy consumption of 5,000,000,000 kilowatt-hours, can be made a reality or even substantially increased.

Power Utilization by Transportation Units

The elimination or the substantial reduction of the losses involved in starting d-c traction motors is a problem that has long concerned transportation engineers. Early in the history of the industry, these losses were reduced by approximately one-half with the adoption of series parallel control, which has the further advantage of providing an efficient half-speed running point.

The past few years have seen rapid developments in the control equipment of urban-transportation units. Competition with rubber-tired vehicles makes imperative the use of accelerating rates that closely approach the limits determined by rail adhesion. In order to maintain smooth acceleration from the starting point until the full motor voltage is reached, it has been found desirable to eliminate transition points. The reduction in first cost and maintenance occasioned by the simplified control of a single motor, is further reason for modern trolley coaches and street cars to use rheostatic control.

The ideal system of control for transportation equipment would provide for the total elimination of control-resistor losses and make available an infinite number of efficient low-speed running points. The need for efficient d-c control seems to be appreciated to a greater extent in Europe than in America. This is evident from the fact that development along these lines has progressed farther, and that the foreign technical press carries more articles relating to this problem than the American technical press.

The Metadyne control, recently furnished on 73 new multiple-unit equipments for the London Passenger Transport Board, is one answer to this problem, although the equipment involved at the present state of development is rather complicated and heavy for general application to small urban-transportation units.

The name "Metadyne" has been given to a type of d-c machine in which special use is made of armature reaction to control machine characteristics. Metadynes have been built to act as rotary transformers of d-c power and applied to control railway equipments. This control is arranged to convert power from constant voltage to variable voltage so as to give any desired speed-torque characteristics to the traction motors from standstill to full speed and from full speed to stop. For example, for the comfort of passengers when using a high rate of acceleration, it is desirable to start with low acceleration, to

increase the acceleration rapidly at a steady rate until a maximum is reached, and then to decrease the acceleration steadily so that when the power is cut off the passengers will not be inconvenienced. Similarly when braking regeneratively, it is desirable to start with a low rate of retardation, increase it to a maximum, and finally to ease off the rate, so that just before stopping the rate of retardation is low. These features can be obtained with the Metadyne in a very smooth manner by varying the natural characteristics.

Experiments have been made with inverters and d-c transformers of the commutator type, in which only light rotating parts are used and the actual transformation of power is accomplished by highly efficient static transformers. Such a device would seem to offer possibilities for producing smaller and lighter units than the metadyne does at present.

There seems to be no fundamental reason why an efficient d-c control cannot be evolved. Perhaps the problem needs only to be emphatically brought to the attention of research organizations. Certainly it should be listed as one of the unsolved problems of electrical engineering in the transportation field in the United States.

Another problem is the definite need for some simple efficient equipment that will convert 600-volt direct current to low-voltage alternating current. On 600-volt multiple-unit cars, especially those operated from third rail, the only method now commercially available for converting from third-rail voltage to low-voltage direct or alternating current is by means of a motor generator set with a 600-volt d-c motor and a low-voltage generator. The ideal solution of this and allied problems would be a device of the nature of a vibrating inverter that would convert from 600-volt direct current to low-voltage alternating current which could be used directly for lighting, or rectified for battery charging, or both. Such a device should have very light-weight moving parts so that there would be no appreciable kinetic energy to dissipate at times of sudden voltage reversals due to third-rail gaps. Means should be incorporated in the device for maintaining constant a-c output voltage with varying d-c input voltage. Inverter tubes would be excellent for this purpose if they could be developed to withstand the high inverse voltages involved and to deliver the necessary power outputs. The problem of rectifying alternating current from such a source to low-voltage direct current, of course, can be solved in a number of well-known ways.

Still another problem is the need, on certain classes of cars and by certain fixed equipment at remote locations, for a small amount of power for lighting and signal lights without using the conventional systems of generation. The conventional systems of power supply such as straight storage batteries, storage batteries and axle generators, or self-contained gasoline engines all seem to be too expensive in first cost and too high in maintenance for the small amount of power required.

A possible solution is the use of primary batteries with some type of fluorescent lamp requiring very little power, yet giving considerable light. Together with these would be required an efficient inverter for the transformation of power to secure alternating current for the operation of the fluorescent lights. The inverter presents a problem because of the high efficiency required with a low power input.

Other problems of power utilization on vehicles would be immensely simplified if storage batteries of greatly improved characteristics for transportation purposes could be developed. While great improvements in storage batteries, both of the lead-acid and alkaline types, have been made in the last 20 years, they have been refinements rather than fundamental changes. What is needed is a battery of radically new characteristics.

Suitable thermostatic control of heat on transportation units is still an unsolved problem. The use of a single thermostat on a multiple-unit car is far from satisfactory, particularly on runs where doors are opened frequently because of stops being close together on one portion of the run, and closed continuously on other portions where there are no stops. A solution of this problem is desired without resorting to the use of forced ventilation.

There is also a great need for a better d-c lightning arrester. At present, the most effective arrester for d-c traction vehicles is the aluminum-cell arrester. No case is known of damage to equipment where the vehicle has been equipped with one of these devices and it was in working order.

However, these arresters are expensive to maintain, require careful maintenance, and in many parts of the country where they have to be kept operating 12 months of the year they must be protected against freezing in winter and overheating in summer, the film being very critical at high temperatures. On 3,000-volt d-c cars and locomotives, 12 of these jars have to be used in series and high short-circuit currents can be caused by jar failures.

For a-c circuits, the Thyrite resistance arrester has been developed and has superseded the aluminum cell. For various reasons, this material cannot yet be used on direct current, but it would seem that a similar material could be developed for use on d-c circuits.

Possible Electrical Solutions of Operating Problems

There is no doubt that electrical engineering can play a considerable part in solving some of the more difficult operating problems of transportation. Consider, for instance, the problem of communication between the vehicle and the dispatcher. With the present state of development of ultrashort-wave radio such communication is entirely feasible, yet out of reach economically. It is obvious that such a development would greatly expedite the handling of emergency traffic problems. Another communication problem, which, however, seems about solved is that of communication between the ends of long freight trains.

The electric fare box is a splendid development. But if an electrical device could be developed that would record and collect the amount of the individual fare in proportion to the length of the individual ride, a veritable

revolution in urban transportation might result. At present, the major part of short-haul rides is lost because the cost of these rides is, as a rule, out of all proportion to the value to the individual patron.

Notwithstanding the use of many clever mechanical devices, the formation of sleet on trolley wire, and on third rails of the over-running type, is in many parts of the country a serious operating problem. Various schemes have been proposed for preventing sleet from forming or, at least, to keep it from sticking tightly to the wire or rail. However, no satisfactory solution has yet been found.

It might be possible to develop some sort of material that would serve as a coating and would prevent sleet from forming. The problem of preventing the current collectors from removing such material, of course, would present considerable difficulty.

On many transportation lines, particularly on subways, the problem of announcing the approaching station is receiving considerable attention. To date, no infallible scheme has been developed that is economically feasible.

The same problem is also present to a certain extent on main line trains, and it is only reasonable to suppose that the train of the future will include some provision to supersede the brakeman's "grunt" which has become synonymous for practically any station on the line.

In connection with signaling and train control, there seems to be a problem of the conduction and detection of very small currents at low voltage through wheels of the free-wheeling type. In general, however, modern systems of train control and cab signaling have been perfected to such an extent that the major problem would seem to be that of financing their installation. Automatic train control is, of course, a unique advantage from the safety standpoint that rail transportation has over all of its competitors. Unsolved problems in this field certainly merit serious consideration.

Another safety problem that should receive attention is that of providing timely and adequate warning in the event of fractured or broken axles.

The problem of recording headways between rail units or trolley coaches at a central dispatcher's office on urban transportation systems has been solved. Such a system, complete with automatic alarms, operating when preestablished headways are exceeded can be installed today at a reasonable cost. The satisfactory recording of motor coach headways, however, still remains an unsolved problem. Such a recorder, functioning without street treadles or attention from the coach operator, is urgently needed.

In general, it seems to the author that the advantages of centralized control and supervision of operation cannot be over emphasized. Such systems can be developed economically and extended over every phase of the power supply and distribution system with great advantage to the transportation service.

Improved Research Instruments

Despite the phenonenal development of scientific instruments, the use made of them by public-transportation agencies is not significant. Something is lacking here. No one questions that the essential factors making for convenience and comfort and therefore for public acceptance of transportation units are speed, smoothness of acceleration and retardation, absence of noise and vibration, illumination, and ventilation, yet the transportation unit is not periodically checked by suitable instruments with respect to these factors.

The performance of new equipment is not even specified and checked with regard to all of these factors. We still rely on our intuition and feelings after a demonstration ride to determine the most comfortable equipment. All of the factors mentioned are physical and therefore susceptible to quantitative measurement. There is no reason why recording instruments presenting a graphic picture of these factors as the transportation unit proceeds along its route should not be developed and used. The significance of these factors will be appreciated only after they have been recorded in some such manner.

One of the important physical factors that we have not yet succeeded in measuring is the presence of objectionable odors or fumes. If someone should develop an objective method of determining and graphically measuring these, we would undoubtedly solve the problem of their elimination.

Notwithstanding the need it is unlikely that instrument or meter manufacturers of their own initiative will develop extraordinary tools for furthering research and development work on transit systems for the reason that the market for such equipment would be so limited that the development would be unprofitable.

The multiplicity of problems facing the industry leads naturally to the vital unsolved problem of stimulating technical developments in the transportation field. Experience has demonstrated the relative ineffectiveness of individual operating companies in the fields of research and progressive achievement. Railway association committees are likewise relatively ineffective. They do excellent work, but the tempo of their achievement due to the very nature of the volunteer type of organization is inadequate to meet present-day competition. Individual manufacturing companies have made noble efforts to keep the public transportation industry abreast of the times. The money they can afford to spend on new development, however, is strictly limited to potential profits they can make from the sale of new equipment. When the prospects for the sale of new equipment vanish, the development program slackens at the very time when it should be accelerated. Somehow, the problem of maintaining an adequate research and development program must be solved.

Illustrative of what might be accomplished by an adequate approach is the result of several years' activity of the Presidents Conference Committee, the new PCC car—a revolution in urban transportation.

The development of equipment and improved standards for railways, as in practically all of the older industries, has been a sort of evolutionary process, that is, improvements have come through the elimination of the cause of faults and complaints. With the limited funds

available for research and development, no other technic was possible. Even with the maximum effort and co-operation only moderate progress is possible by using such a technic. The activity of various technical committees, through interchange of experience and ideas, stimulates and accelerates the evolutionary method, but the results are naturally the refinements of existing equipment instead of the development of revolutionary new methods and equipment.

If the necessary funds, time, and organization were available it would be possible to attack this problem in an entirely different way. The broad general objective could be established "a priori" or by means of a consumer or patron survey of results that should be accomplished. Research men and scientists could then set about obtaining all factual data relevant to the accomplishment of these results. After the physical factors entering into the solution had been isolated, performance specifications could be set up. Up to this time, no consideration need necessarily be given to past experience or to equipment available at present. The newly evolved specifications would provide the necessary standards by which to judge not only the performance of existing equipment, but also of all proposed equipment.

It is vital to observe that there is nothing final or absolutely conclusive about performance specifications developed in this way. The whole technic and development is based upon a premise that is constantly shifting with public sentiment. If noise were disregarded by the public yesterday but its elimination considered vital today, our performance specifications must be changed accordingly.

An organization designed to cope with problems in such a manner must be permanent and its activity continuous. If its financing were a charge against operating expense development would be greatly stimulated, and furthermore the acceptance and actual use of new developments would be expedited for the following reasons:

1. Operating companies are in direct competition with other forms of transportation and therefore have a keen interest in improving their competitive position. They are able to sense more quickly and accurately public demands in transportation than the more remote manufacturers of equipment. They would therefore initiate more quickly development work actually needed to meet public demands.

2. In an effort to realize on their contributions to the joint development fund, operating companies would do everything possible to put new developments into actual service.

3. Because new developments would not be loaded with manufacturers development costs, the initial cost of new equipment would be greatly reduced with consequent savings in fixed charges.

Such an organization supported by the operating companies and functioning with adequate resources would inevitably present to the manufacturers unsolved and worth-while problems of the industry that we cannot even comprehend today.

Power Plants Afloat

NO APOLOGIES need be offered for modern marine machinery. The industry is keeping well abreast of power developments. The average shore engineer would be favorably impressed with the power plant aboard any modern ship. Of course, in viewing a ship's installation one must keep in mind the limited space and the inevitable conflict that must occur in reconciling the different demands upon that space and the weight allowance for machinery in any given model. Certainly the fundamental axiom of ship construction is that each demand must be compromised in order to arrive at a buoyant, stable, and workable ship. Furthermore, it should be axiomatic that there must be employed afloat much larger factors of safety than are needed in shore design.

Just as in shore establishments, afloat there are steam plants, Diesel plants, combination steam and Diesel, and a constantly increasing use of electricity for the distribution of power to distant units, and for reduction gears.

For the main propulsive units, which account for 80 per cent or more of the power utilization, there are steam plants driving turbines through mechanical reduction gears; steam plants driving generators, which in turn drive the propeller through a motor or so-called electric drive; the straight Diesel drive; the Diesel drive through mechanical reduction gears; and the Diesel drive through electrical reduction gears, if they may be so termed. The race between the Diesel and the turbine is so close, from the standpoint both of reliability and economy, when the 20-year life of a vessel is considered, that the choice between them becomes largely a matter of personal preference. The same condition is not quite true of the choice between mechanical or hydraulic reduction gears and electrical coupling. There is no question but that electric losses of such connections are somewhat greater than the friction losses of well-made reduction gears. On the other hand, the author* is of the opinion that the flexibility and the elimination of vibration inherent in the electric gear more than compensate for the difference in efficiency in the case of many merchant ships and afford the electric connection much attraction for military purposes.

In departments of the ship other than the engine room, there seems to be slight justification for any but electrical equipment. Electric winches, electric steering engines, electric galleys, because of the flexibility of electric-power conduits, as compared with the awkwardness and risks of conducting steam about a ship, have left the steam-driven winch and the oil-fired galley range in the limbo of the past.

* From a paper "Some Problems in the Design and Operation of Merchant Vessels," by Robert C. Lee, published in the *Transactions* of The American Society of Mechanical Engineers, February 1940, pages 63-74.

Note on Earnshaw's Theorem

LEWI TONKS

Many have seen the "electromagnetic levitator" in the General Electric Company's "House of Magic" demonstration lectures. In this demonstration, an aluminum disk is stably supported in an alternating magnetic field under the repulsive force between the induced eddy currents and field.[5] Another and related problem is reflected in several recent and serious, but inevitably futile, attempts to achieve stable suspension in space under the forces of permanent magnets alone. This article sheds further light on the basic theory involved, which was formulated a century ago by Samuel Earnshaw and seems quite largely to have been overlooked.

EARNSHAW'S THEOREM as quoted by Maxwell[1] states that: A charged body placed in a field of electric force cannot be in stable equilibrium. In general it has received rather scant attention, and Earnshaw himself has been neglected, by those judged to be his compatriots, in the "Encyclopedia Britannica."

The chief theoretical importance of the theorem has arisen from its bearing on the static model of the atom, for it proves the impossibility of such an atom composed of charges that exert Coulomb forces on each other.

This may explain the partial neglect which the theorem has suffered; the static atom has long since ceased to be an issue. But the recent development of ferromagnetic materials having enough remanence and coercive force so that the repulsion of one permanent magnet for another is greater than its weight lends fresh importance to that theorem. These magnetic forces are of a magnitude to interest the engineer, who may look upon them as a way of overcoming gravity and attaining the free stable suspension of bodies in space. It therefore becomes necessary to point out that all such attempts to use simply the force between permanent magnetic poles, or between poles and a fixed field are doomed to failure because the magnetic field obeys the same law as the electric field.

The restrictions are even narrower than this, for no flexible assemblage of magnetic poles, in which readjustments in position of the poles in the group can occur, can be stable in either a fixed field or in the field from another such assemblage. The proof of this statement is implicit in Maxwell's proof, but it is worth while briefly to recapitulate this demonstration in terms of magnetic poles instead of electric charges and to point out the relation of the theorem to two devices that achieve the stable suspension of bodies in free space.

Consider two assemblages of poles, I and II. Let the m poles of assemblage I be interconnected by any system of ropes and pulleys, springs, rods, levers, etc., subject only to the restriction that the force field shall be conservative. Let the same be true of the n poles of assemblage II.

Following Maxwell's treatment, we first suppose the poles within I to be temporarily immobilized, and the same for II; second, we suppose that both I and II are prevented from rotating and only allow translation of I relative to II. By applying Laplace's equation to the magnetic potential of assemblage II at the points where poles of I are located, it appears that there are always directions of displacements for I in which the initial change in the potential energy M is a decrease. That is, $\partial M/\partial r$ is negative infinitesimally close to the position of I if not at the position itself. Hence I tends, when slightly displaced, to move in such a direction under the force $-\partial M/\partial r$, and any equilibrium is unstable. Instability is therefore all the more present when the two assemblages are free to rotate.

Now let I move a distance δr in such a direction. Then let us release the temporary constraints from I and II so that the poles within each assemblage can move. Such motion will lower the potential energy by an amount that may be denoted by $C\delta r$. Accordingly, the total increase in potential energy accompanying the displacement δr is $[(\partial M/\partial r) - C]\delta r$ so that the restoring force is $(\partial M/\partial r) - C$. Since C is positive, the instability represented by the negative $\partial M/\partial r$ is *increased* by the flexibility in the two groups of poles.

It should be noted that the presence of induction effects of the field on the poles is covered by this treatment, for these changes can be simulated by the proper elastic connections between infinitesimal poles. In addition, the presence of a gravitational field acting on one assemblage alone, as is the case if the other assemblage is attached to the earth, cannot create stability, for the gravitational field itself obeys the inverse-square law.

Any restraint between the two assemblages of poles of course, may give stability. In particular, the reduction of the problem to two dimensions, as by Ewing with his floating magnets, immediately makes stability possible, because confining one assemblage to motion in a plane is a restraint. We need only arrange that $\partial M/\partial r$ is positive for δr in the plane and negative for δr perpendicular to it, and confinement to the plane will supply the stability that the magnetic field alone lacks.

Two types of stable free suspension using magnetic forces are known to the author, and it is of interest to note their relation to the foregoing proof. An example of the first type[2-4] employs an electromagnet (or coil) to support a permanent magnet, or soft-iron armature, the strength of the electromagnet being continuously and automatically readjusted by a control system to hold the permanent or induced magnet at a fixed level. The necessary changes in pole strength are in the opposite sense to the induction effects which have already been mentioned. Since those induction effects correspond to a positive value for C, the forced effects correspond to a negative C, which, if large enough, can achieve stability.

The second device is the electromagnetic levitator,[5] in which an aluminum disk is stably supported in an alternating magnetic field under the repulsive force between the

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induced eddy currents and the field. Here the suspended "poles" are solely those produced by circulating currents. Although this situation is far more complicated, we can at least recognize that the Coulomb law no longer applies to the floating disk, for the closer approach of disk to field coils increases the eddy currents so that the repulsion increases faster than according to Coulomb's law. And small shifts of the disk into other parts of the field cause the creation of new "poles". In this case as in the previous one, the changes in pole strength correspond to negative (magnetic) induction.

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A Modern Aspect of Engineering Education

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An engineering education will fail in its purpose if it gives mere formulaic information; it must build a man who can accept the responsibilities a modern world thrusts upon him, says this engineering-college dean who describes the program established at one university to give the young engineer not only the technical knowledge his profession demands, but also that broader education required to enable him to meet the demands of this modern world.

THE ENGINEER is regarded in the world of today as a man who has accomplished miracles. No one would criticize him for lack of imagination or deficiency in ability to develop mechanical or technical works. Whatever criticism is levied against him is levied from the standpoint that he has not applied the same skill that he has used for the solution of technical problems to the social, economic, and human problems that affect our life today. Yet, it is incumbent upon him that he do so if the definition that formerly hung in the library of the Engineering Societies Building in New York City is a valid one. It places in first position the importance of directing men as it proclaims: "Engineering—the art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race".

In the following discussion it is this broad conception of the realm of the engineer that must be kept in mind in contradistinction to the more narrowed concept of the technician or the designer engaged upon routine work or the man engaged in ordinary testing. We must consider that the real engineer of today is a man who thoroughly understands not only the fundamental technical information pertaining to his profession, but also is educated in a much broader field. Only then can he cope with the social, economic, and psychological factors which ever will present themselves when various tasks are brought to him for his consideration. What wonder, therefore, that the engineering educators of today look critically at the curricula of the various engineering institutions of learning in an effort to determine what might be done so that the engineer shall be considered more than a technical expert. No profession has scrutinized more carefully and critically the educational methods that apply to the men who contemplate entrance into its ranks than has the engineering profession. In 1922, after many years of discussion, an extensive investigation of the educational methods in engineering was begun under the auspices of the Society for the Promotion of Engineering Education. It is impossible to attend a meeting today of any of the national professional engineering societies without at least some reference being made to engineering education.

Society Criticizes the Engineer

These references are of a varied nature. Sometimes the engineer is accused of being so interested in his professional work and in doing things of a technical nature that he has neglected the duties of citizenship. Sometimes he is accused of being far more interested in mathematical and physical phenomena than he is in the cultural, social, and human problems of the world about him. We are told that he is lacking in personality, in social consciousness, in artistic taste, in appreciation of financial problems, and in foresight pertaining to human adjustments. In fact, he is frequently blamed for many of the present ills of modern society.

We cannot accept these criticisms as valid, for in every worth-while movement today, the engineer does take an active part. We cannot agree with the statement that the engineer must also be a banker, a lawyer, a sociologist, as

Essential substance of an address presented at the AIEE Southern District meeting, Miami, Fla., November 28–30, 1938; subsequently revised and brought up to date.

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well as a good engineer. We do not expect the economist to know engineering. The lawyer is hardly expected to solve engineering problems. The sociologist does not build bridges. Each of these men has his field; and if one is to become expert in any field, he cannot thoroughly know all the rest. This applies to the engineer as well. The engineer designs and supervises the construction of a great bridge or a large dam, a power plant, a system of roads, a transmission line, a radio station; or he takes an active part in many of the major activities that come definitely within the province of his profession. If he is to become sufficiently expert in the technical phases of his subjects, if he is to secure the experience, the imagination, and the ingenuity that will help build these wonders of our age, how can we expect that he can become adept in those other professions which also must take a lifetime of earnest effort, of hard work, and much study to master them.

Purpose of an Engineering Education

What then should be the purpose of an engineering education? Surely it must be more than just another step in the student's educational program, more than just another step between high school and professional life. It comprises probably the greatest period of transition in a man's development. Shall it be along narrow lines to fit him quickly into the industrial world? Then shop courses and minute specialization will quickly assist the young man to step into production in industry. It must be broader than this. It should prepare the young man for the tomorrow of his whole life. It should be the foundation upon which must rest not merely the floor above, but the entire superstructure. An engineering education will fail in its purpose if it gives mere formulaic information. It must build a man—a man who can accept the responsibilities a modern world thrusts upon him. Success in his life's vocation definitely will depend on his ability to assume these responsibilities. Those graduates of our institutions who wonder why success does not come to them—are they not frequently unable to cope with the demands of the present-day world? The engineer obviously must learn and know the technical matter that is unique to his profession; but if more than mediocrity is to be his reward, then he must develop himself in a broad manner so as to be able to solve problems by weaving together technical data with social, economic, and psychological factors. What is applicable to engineering is likewise applicable to the practitioner in many other professions. No problem is solved until its solution is tested by performance and the new problems brought about by its innovation have been solved. This is an endless chain, and the adjustments must be many—and he who is to be the "captain" must be the superman, indeed. Modern education should take cognizance of this, and no program should be adopted that fits a man into a groove that is too narrow. Technical knowledge alone cannot suffice.

There are certain broad fields of knowledge with which all professional men should be acquainted. Every preprofessional course should demand a reasonable conception of the correlated problems in the fields of the social, physical, and biological sciences. Add to these an appreciation of the so-called humanities, an ability to express oneself well in written and spoken English, and a conception of mathematical relations and we have a basic training that will form a foundation for many types of superstructures.

Analyzing the Entering Student

A question arises at once: Can all students benefit from such a program? Perhaps not. Certainly any man having the ability to benefit from a college education should benefit from a program that makes not for narrow specialization and a limited outlook, but which gives him a conception of not only his chosen field but also the adjacent territory as well. Perhaps to the college this question will also emphasize the need for a greater scrutiny of entering freshmen so that those who probably would derive little advantage from the time spent at the university might be shunted into other paths. Many state institutions find it difficult to discriminate against state high schools, even though they have found that from some of them come students so poorly prepared in basic subjects required of university students, that they fail, or—and this is probably worse—that they stumble through a four-year course barely passing in a majority of the work. Sometimes this is due to the student's lack of ability, but not always. Where to place the blame for this we are not at this moment to determine, but that there is a need for educational guidance is definitely shown.

Yet college procedure is highly stereotyped. Few colleges pay much attention to the entering student except to make sure that he is a high-school graduate. He must choose his career on entering a university, even though he is not prepared to do so. Usually his choice of curriculum is based upon hit-or-miss methods. How much better would it be if the student had an educational background that would give him general information of the several fields of knowledge so that he might more intelligently select his vocation. Thus, educational guidance and vocational guidance are closely related. Both must be based upon definite information of the knowledge and aptitudes of the student. This can only be secured by thoroughly examining the entering student and by closely following him during his educational program. Should not the college use some means of "inspecting" the entering "raw material"? Should all material be accepted regardless of whether or not it is suitable? Should all material go through identical processes? Obviously not! Poor incoming material, hit-or-miss methods in selecting a career, coupled with a narrow technological training will seldom produce more than "slide-rule artists" and technicians.

The various curricula of the engineering institutions of the United States are indicative of many approaches to overcome these problems, and while it would be well to consider many of them, this article deals with a relatively new one which has been introduced at the University of Florida. It gives a new approach to some of the problems that have confronted us, and it seems to give an answer to many of the criticisms that have been levied against engi-

neering educators. In it will be found a definite attempt to prepare the student not only for entrance to the engineering profession by giving him a well-rounded technical education, but also to give him many subjects that tend to make for better citizenship and for an appreciation of the problems of the modern world.

Adjustment of Curricula to Meet Student Needs

Certainly it does not have for its purpose the turning out of more engineers—but rather, better engineers. There will be found some application of what might be called "engineering principles" in the selection of "raw materials" and in what might be called the "operation of the plant". Every incoming student to the University is given an examination. Some of them are told that it is improbable that they will benefit from a college course and are advised not to matriculate. The remainder, through individual conferences with the dean or his representative, secure educational guidance in planning their courses. This corresponds to what in industry would be an "inspection and selection of raw materials".

Inspection of the entering students is made through a series of comprehensive examinations, in many cases even before he leaves high school. Results of such examinations together with the high-school record gives much information that is of value in analyzing the new student. The student who has done only mediocre work in high school is given courses in "man and the social world", "man and the physical world", English, "man and his thinking", and "elementary mathematics". If he shows aptitude and a fair knowledge of the physical sciences and of mathematics some of these courses may be omitted. Thus, for superior students adequately prepared there is no duplication of material already learned; but for the student not so well prepared, the survey course in the physical sciences allows better work to be done in the advanced courses. The survey course in mathematics does the same.

Thus, as the result of the inspection of the incoming "raw material," only that which is ready is built at once into the finished product. The rest is further processed before being utilized in making the final product. While for those men who have chosen a career and who have both the necessary aptitude and information there is no delay, for others the foundation must be prepared before the superstructure can be placed on it.

Then, too, since the superior student can forge ahead more rapidly than the average student, he is permitted to do so. In his sophomore year a course in the humanities and one in the biological sciences are given him. In consequence, at the end of the sophomore year the superior student has received the basic training in the fundamentals of engineering (English, calculus, chemistry, physics, drawing, descriptive geometry, and an engineering elective course) and in addition he has secured courses in the other broad fields of learning. Therefore, he has utilized his superior ability for securing some liberal education coupled with the necessary pre-engineering information that he must have for pursuing an engineering career.

But what about the nonsuperior student, the student who is not so well prepared, the student who has not determined his future vocation? These men will require an additional year, but this is not extra time required for making up failures. In some instances this time is devoted to securing better preparation for the courses in mathematics and the physical sciences which follow. In others the load is reduced and the student goes ahead at a less rapid pace. In each instance the student's needs are considered and he is given educational guidance as he proceeds.

Educational Guidance Parallels Vocational Guidance

Closely allied to educational guidance comes vocational guidance; and although there is a close relationship between educational guidance and vocational guidance, they are not the same. Frequently, a student comes to a university with an apparent desire to enter a particular curriculum. He may wish to become an engineer because someone has told him of high remuneration involved, or the glamour connected with some parts of this profession. As to his aptitude and general fitness for this profession, that is left to chance. From interviews with entering students it has been quite surprising to find what little reason, judgment, and common sense the student uses in the selection of his life's work. But most vocational guidance supposes that the student has sufficient knowledge to plan his career. Unfortunately, he usually has not. The broad education that students receive during their first few years allows them to become far better acquainted with various forms of man's endeavor and they then can make a much more intelligent choice of their life's work. The sorting process previously mentioned thus is continued.

Some of the material finds its way to the colleges of engineering, business administration, agriculture, and others. Certainly, many who thought they would like to become engineers have found that they probably would prefer work in other fields. Still others who thought they would not like engineering now find a preference for this work. The case of one student in particular who said he had a dislike for engineering, on entering the University, is an example of this. His dislike was based primarily upon a serious deficiency in mathematics and physics. Yet, this same student showed excellent aptitude for these courses in the general college and will probably make a successful engineer. His dislike for mathematics and physics was not due to lack of ability in these fields, but was due to poor preparation—perhaps due to poor teaching before coming to college.

This sorting process thus allows differentiation to be made between various types of students and enables adjustments to be made better to qualify them for fields in which they are best fitted. Through frequent conferences with members of the faculty, students are given vocational guidance only after some educational groundwork has been laid, so that an intelligent decision of a vocation based upon knowledge can be made.

A Terminal Point at the Halfway Mark

This sorting is carried even further. It is recognized that after two years in college some men might best terminate their collegiate program and go home. However, at most universities there is a certain stigma attached to the man who does not complete his college course and receive a degree. Now, at the end of the two-year general-college program at the University of Florida there is a definite terminal point, and those who reach it receive a certificate—an honorable discharge for those who leave. It gives them an easy way out. In other words, there is an inspection halfway through the process and some by-product recovery.

Mere graduation from the general college, however, is not sufficient for entrance into the upper division of the college of engineering. The student must satisfy the entrance committee of the engineering college that he is qualified to pursue a curriculum leading to a degree in engineering. Students who have secured mere passing grades in the lower division are not admitted to the engineering college. Students who have slight deficiencies may be admitted on probation. The student thus is given a stimulus to do better work. Mere "getting by" is definitely discouraged. Students, therefore, cannot be satisfied in just passing courses, but often prefer to proceed more slowly and so do work of a better quality. Many men now on entering college plan from the very beginning on a five-year college program.

It would be a mistake to assume that barriers are thrown in the way of those students who show a definite interest in engineering, and who show they have the required aptitude as the result of the entrance examination. Those students who have shown knowledge and aptitude in the sciences and mathematics are allowed to proceed directly with prescribed engineering subjects. Such men take heavy schedules and can complete the entire engineering course in four years. Their curricula will have included courses in the social and economic phases of modern life without in any way sacrificing instruction in the technical aspects of engineering. Five years, however, are required by most students to secure an engineering degree, but this has been true for most students even with the curricula in effect many years ago.

Modern Methods for Increased Efficiency

The courses in the general college have been carefully planned, and improved pedagogical methods are in use. Every attempt is made to have the student use his initiative. The amount of material covered in a particular course by different students varies greatly, depending primarily upon their interests and abilities. Grading is not on the basis of mere attendance, but is primarily based upon achievement—comprehensive examinations being used in many courses for making such measurements. In fact, the student may register for some examinations without attending the courses, and some students find it possible to pass a few courses in this manner. Each student is given considerable latitude in developing himself according to his own individuality.

Although the last two years of the engineering program do not differ materially from the standard programs of other engineering colleges, the influence of the educational program outlined herein definitely is felt in the upper-division work. It seems that the quality of the work is better. Only students who show reasonable aptitude and who can demonstrate by examination that they are in a position to benefit by a course in basic mathematics are assigned to this course. Most of the students of the type who formerly just "got by" are weeded out, and a larger proportion of those taking basic mathematics and calculus pass with grades above the mere passing grade. This improved work in mathematics would necessarily be reflected in the courses that follow in engineering.

In the upper division more and more efforts are being made to place courses on a project basis, and to give the student more opportunity to develop individual resourcefulness. Courses are planned realizing that an engineer first of all must know the technological material that is basic to his profession. Then upon this must be built that philosophy of engineering which should enable him to handle not only materials and methods, but also men and money. Courses, especially in the general college, are at the present time all in a formative period, and each day brings new changes—changes which it is hoped will give industry men with a good knowledge of fundamental engineering; men with a thorough knowledge of engineering technology; men well versed in the philosophy of our profession; but above all, men who have a social consciousness so that they may become good administrators and good citizens, for otherwise they are mere "Frankensteins" and their work will come to naught.

In the new program the work of the college does not stop when a man is graduated, but the college will attempt to give what might be called postgraduate guidance. While in the past this has been limited almost entirely to an attempt to secure employment, this will now go further and the graduates will receive assistance in adjusting themselves to the industrial world, and assistance in continuing their education after graduation. As the engineering educator finds himself less and less occupied with the problems of the entering student, he can devote more and more efforts to the alumni, and here it seems beneficial work can be done.

The world today challenges the engineer. It is not satisfied that he bring his brain children into being; it demands that he guide and control them. The works of the engineer are all about us, but the control of these works, for the most part, is in the hands of other men. The engineer of tomorrow, therefore, must be educated broadly enough so that not only can he guide the destiny of his own work, but also in this modern scientific age he must perhaps become the guide of the world about him.

The program that has been described attempts to give the young engineer not only the technical knowledge his profession demands, but also that broader education in the arts, humanities, and associated sciences, which it is hoped will fit him not only for his life's career, but also for the other duties that the world now expects of him.

Of Current Interest

Industry • • • •

$200,000 for Arc-Welding Papers

According to announcements currently being distributed by the James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, a total of 458 cash awards amounting to $200,000 will be made to the authors of winning papers in an arc-welding prize paper contest which opened January 1, 1940, and which is scheduled to run for two and a half years, until June 1, 1942. By its own statements:

"The object and purpose of the James F. Lincoln Arc Welding Foundation is to encourage and stimulate scientific interest in, and scientific study, research, and education in respect of, the development of the arc welding industry through advance in the knowledge of the design and practical application of the arc welding process. . . . . Many of the benefits of progress in recent years have been due to the scientific development and application of arc welding. Arc welding so lowers the cost of manufacture that products which were luxuries yesterday are commonplace today. Further progress in developing and applying arc welding in the vast undeveloped field of its possible application will transform the extravagances of today into the common good of tomorrow."

Top prize for the best all-around paper is announced as amounting to $13,700; at least 223 honorable mentions will receive $100 apiece.

For the classification of subject matter, 12 industrial classifications have been established: automotive, aircraft, railroads, watercraft, structural, furniture and fixtures, commercial welding, containers, welderies, functional machinery, industry machinery, and maintenance. These 12 classifications have been subdivided into a total of 46 divisions to broaden the basis of possible entry into the competition.

Although electric arc welding is emphasized in the literature, it is understood that it is the desire of the Foundation to bring out social benefits and possibilities for better or more economical products resulting from arc welding as a process, rather than to emphasize in any way mere magnitude of any one arc-welding application.

A 48-page illustrated booklet descriptive of the program is said to be available on request to the James F. Lincoln Arc Welding Foundation, Post Office Box 5728, Cleveland, Ohio.

Technical Magazine in Spanish. To acquaint engineers and industrialists in Latin American countries with technical developments in the United States, a monthly magazine, "La Ingenieria e Industria en los Estados Unidos" (Engineering and Industry in the United States) has just begun publication. Issued in Spanish by the Pan-American Economic News, Inc., 80 Broad Street, New York, N. Y., the new magazine is interested in receiving articles suited to its needs from AIEE members and others.

From AEC • •

ITEMS appearing under this heading are from the news service of American Engineering Council.

New Quarters

Effective February 15, American Engineering Council shifted its offices in Washington from the old quarters which it had occupied since 1922 to a new location at 919—17th Street, N.W., where it will occupy a building jointly with the American Forestry Association and immediately adjoining the Army and Navy Club.

While the primary motive for the move was the expanding needs of the American Council on Education, which had been sharing the building at 744 Jackson Place, AEC itself will realize a number of benefits that will more than offset the trouble of moving. The new offices are fully as convenient, being located only a block distant from the old, and will provide facilities better adapted to the needs of Council, which requires much storage space for the valuable records accumulated during the past 20 years. These are now more readily accessible. In addition, there will be a distinct saving in rental charges, making it possible to devote a larger proportion of the annual budget to productive activities.

Education • • •

Engineering for Doctors. Summarizing the latest reports of the Harkness family's Commonwealth Fund's philanthropic activities in the field of U. S. public health and medical research, *Time* magazine for January 22 points out that "One interesting award sends a man from a physiological laboratory to a school of engineering so that he can bring back from hydraulics and mechanics principles and techniques applicable to the study of blood pressure, blood flow, and the like."

Power Conference. Sponsored annually by Armour Institute of Technology for industrialists and educators all over the country, the Midwest Power Conference will be held this year at the Palmer House, Chicago, Ill., April 9 and 10. The conference is conducted with the co-operation of Iowa State College, Michigan State College, Purdue University, State University of Iowa, University of Illinois, University of Michigan, University of Wisconsin, the Chicago Sections of the AIEE and American Society of Mechanical Engineers, the Western Society of Engineers, and other engineering societies. Subjects of special sessions include small power plants, electrical transmission, power-process, fuel problems of power plants, and hydro power. L. W. W. Morrow (A'13, F'25) regional editorial director, McGraw-Hill Publications, Chicago, will be speaker at a joint luncheon of the conference and the AIEE Chicago Section on April 10.

Other Societies •

Cumulative Index. A cumulative author and analytical subject index of volumes 1–10 of the *Journal* of the Acoustical Society of America, October 1929 to April 1939 inclusive, has recently been issued for the Society by the American Institute of Physics. The volume also includes author and subject indexes of contemporary literature on acoustics, as listed in the *Journal* 1937–39. Copies of the index may be secured from the publications manager, American Institute of Physics, 175 Fifth Avenue, New York N. Y.; price $3.00 per copy.

Future Meetings of Other Societies

American Chemical Society. Annual meeting, April 8–12, 1940, Cincinnati, Ohio.

American Institute of Chemical Engineers. 32d semi-annual meeting, May 13–15, 1940, Buffalo, N. Y.

American Physical Society. 234th meeting, April 25–27, 1940, Washington, D. C.

American Society for Testing Materials. 43d annual meeting, June 24–28, 1940, Atlantic City, N. J.

American Society of Civil Engineers. Spring meeting, April 17–19, 1940, Kansas City, Mo.

American Society of Mechanical Engineers. Spring meeting, May 1–3, 1940, Worcester, Mass.

Semi-annual meeting, June 17–21, 1940, Milwaukee, Wis.

Association of Iron and Steel Engineers. Annual Spring Conference, April 1–2, 1940, Cincinnati, Ohio.

Edison Electric Institute. Annual meeting, June 3–6, 1940, Atlantic City, N. J.

Electrochemical Society. Spring meeting, April 24–27, 1940, Wernersville, Pa.

Midwest Power Conference. April 9–10, 1940, Chicago, Ill.

Society of Automotive Engineers. Summer meeting, June 9–14, 1940, White Sulphur Springs, W. Va.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

The Use of the Millibar In Weather Bureau Reports

To the Editor:

The engineering societies have cause to object and protest to the current action of the United States Weather Bureau in putting out barometric data in terms of millibars instead of inches of height of the mercury barometric column on the following grounds.

This change is the antithesis of standardization in that it replaces an ancient and universally used standard of this and other English speaking countries by another of limited acceptance which offers no advantages from the point of view of logic, scientific legitimacy, or convenience in use, except possibly to a small coterie of meteorologists interested in international comparisons of such data. Engineering standards and rules are expressed in terms of barometric height. This encroachment of a Government Bureau on a standardizing matter, which is particularly in the province of the engineering societies, should be resisted.

The introduction of the millibar unit renders impossible the direct comparison of Weather Bureau data with the readings of all barometers. This lessens the value of the service to the public, which is ostensibly the object for which the Weather Bureau spends a considerable amount of public funds. Vacuum gauges as well as barometers are graduated in inches of mercury column.

The procedure as described in an official letter dated January 26, 1940, is as follows: "Mercurial barometers used by the Weather Bureau are graduated in inches. Readings made in inches are converted into millibars before being reported. The millibar is internationally employed for reporting barometric pressures."

In Form 4090, "The Use of Millibars" the following statements occur: "In earlier years it was customary to express atmospheric pressure in inches denoting height of the mercury column in the barometer. Since the inch is a unit of length, and not a unit of pressure, the use of inches for expressing atmospheric pressure is unsatisfactory for modern purposes. Several years ago the millibar, which is the standard unit of pressure, was adopted for aerological observations, and since then its advantages have resulted in its adoption by nearly all countries for use in expressing barometric observations taken on ships at sea as well as at regular weather stations on land.

"Because of the delay incident to converting millibars into inches, with the increasing number of weather reports from ships at sea and from Canada and other countries, the Weather Bureau on July 1, 1939 adopted the numerical code which uses millibars and began publishing these units on its Washington weather map. This permits speedier handling of its reports and greater accuracy in analyzing weather situations for the purpose of issuing weather maps, forecasts, and advices."

Fault can be found with the foregoing statement in a number of particulars, some of which are quite obvious. Note should be made however, of the statement that the millibar is "the standard unit of pressure." This statement is inaccurate. There are various standard units of pressure such as the pound per square inch, and the height of the barometric column. The millibar is a derivative of the theoretical centimeter-gram-second system of units which has never entered into general practice in science and engineering, and hence cannot be called the standard system. The international meteorologists may have agreed to exchange data in terms of millibars. No fault can be found with this, but it does not make the millibar the standard unit of pressure.

The plea is made that the use of the millibar tends toward greater accuracy. It is difficult to see why multiplying the readings of an instrument by a constant makes them more accurate. Such an operation even introduces the chance of a numerical error.

In the conversion table from millibars to "inches" the Bureau follows a practice which by implication it elsewhere condemns. This table makes no statement as to the value of the gravitational constant on which it is based. Such looseness of terminology and incompleteness of statement do not add to the strength of the Weather Bureau's argument.

The foregoing considerations suggest the thought that the Weather Bureau is willing to subordinate the interests and convenience of readers of barometers and students of its own charts and tables to its own facility of operation.

It is urged that the engineering societies should use their powerful influence to resist, in behalf of engineers and of the public affected, all tampering with existing, generally adopted standards, except for such compelling reasons as do not exist in the present case.

CLAYTON H. SHARP (A'02, F'12)

(Formerly President, United States National Committee, International Electrotechnical Commission)

Obtaining Test Constants for Induction Motors

To the Editor:

In manufacturing practice it is often necessary to obtain the constants of an induction motor from test measurements on a finished machine. This may be for the purpose of fault location, finding manufacturing errors, or for duplicating the performance of a completed machine with another set of punchings.

Such a method was given by C. G. Veinott for single-phase motors in ELECTRICAL ENGINEERING for December 1935, page 1302. Another procedure is given in the AIEE standards for polyphase induction motors. These involve accurate readings of slip which are not always convenient to take. They also have the objection that the leakage reactance is treated in the same way as an ordinary impedance. Because of this, they lead to a certain amount of error which becomes more marked as the number of poles increases or the frequency decreases.

Because of their convenience and the fact that they seem not to be generally known, there will be given in outline a method alternative to that of Veinott for single-phase, and another for polyphase motors. In the derivation, core loss and saturation are neglected.

Readings Required: Single and Polyphase.

1. D-c resistance of primary in ohms per phase $= r_1$.

2. No-load:	volts	amperes	watts
	E_0	I_0	W_0

(all per phase).

3. Locked:	volts	amperes	watts
	E	I	W

at rated or reduced voltage and rated frequency, all per phase.

(*a*) Calculations: single-phase:

$$Z=\frac{E}{I}, \quad R=\frac{W}{I^2}, \quad X=\sqrt{Z^2-R^2}$$

From the theory of the single-phase motor;

$$i_m \cong \frac{2-K_r}{2} I_0$$

Assume a value for K_r and correct later. This is done by repeating the work that follows two or three times until it converges to its final value.

Magnetizing reactance with open rotor = mutual + primary leakage reactances,

$$X_0 \cong \frac{E_0}{i_m}$$

$$K_r = \frac{X_0 - X}{X_0}$$

$$a = \frac{R-r_1}{X}$$

$$b_1 = \frac{1-(1-K_r)(a^2+1)}{K_r}$$

Leakage reactance,

$$X_{\text{corrected}} = b_1 X$$

Calculate new K_r and repeat until convergence.

$$b_2 = \frac{1}{K_r}\left[\left(\frac{X}{Z'}-\frac{Z'}{X_0}\right)^2+\left(\frac{R-r_1}{Z'}\right)^2\right]$$

$r_2' = \dfrac{R-r_1}{b_2}$ = crossfield theory value of rotor resistance. Includes skin effect if X does not change much from locked to idle conditions.

The revolving field theory value is one-half of this.

If desired, b_1 and b_2 can be plotted against a for different values of K_r.

(*b*) Calculations: polyphase:

$$Z=\frac{E}{I}\ ,\quad R=\frac{W}{I^2}\ ,\quad X=\sqrt{Z^2-R^2}$$

Magnetizing reactance = sum of mutual and primary leakage reactances,

$$X_0\cong\frac{E_0}{I_0}$$

$$K_r=\frac{X_0-X}{X_0}$$

Let

$$a=\frac{R-r_1}{X}$$

then

$$b_1=\frac{1-(1-K_r)(a^2+1)}{K_r}$$

$$X_{\text{corrected}}=b_1X$$

$$K_{\text{corrected}}=\frac{X_0-X_{\text{corrected}}}{X_0}$$

Physically K_r is equal to the coupling coefficient, $\frac{M^2}{L_1L_2}$.

When r_1 is considered as external series resistance (B. De La Tour),

$$\frac{K_rE}{(1-K_r)X_0}=\frac{K_rE}{X_{\text{corrected}}}=\text{circle diameter.}$$

Let

$$Z'=\sqrt{(R-r_1)^2+X^2}$$

Then

$$b_2=\frac{1}{K_{\text{corrected}}}\left[\left(\frac{X}{Z'}-\frac{Z'}{X_0}\right)^2+\left(\frac{R-r_1}{Z'}\right)^2\right]$$

$$r_2=\frac{R-r_1}{b_2}=\text{rotor resistance.}$$

(Includes skin effect if X is about the same at no-load and short-circuit.)

When X is known it can be broken up into components x_1 and x_2 for classes *A*, *B*, etc., as suggested in the induction motor standards.

Roughly,

$$x_1\cong x_2\cong\frac{X}{2}$$

or better,

$$x_1\cong x_2\cong\frac{1-\sqrt{K_r}}{1-K_r}$$

As no workable method for obtaining x_1 and x_2 from test is known, and since the behavior of a motor is largely independent of the distribution in leakage between primary and secondary, this division is sufficient for most purposes. This division is not necessary for drawing the circle diagram.

A. F. Puchstein (A'20, M'27)

(Consulting Engineer, Robbins and Myers, Inc., Springfield, Ohio)

Library • • • •

OPERATED jointly by the AIEE and the other founder societies, the Engineering Societies Library, 29 West 39th Street, New York, N. Y., offers a wide variety of services to members all over the world. Information about these services may be obtained on inquiry to the director.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

AT&T, THE STORY OF INDUSTRIAL CONQUEST. By N. R. Danielian. New York, The Vanguard Press, 1939. 460 pages, maps, tables, 10 by 6 inches, cloth, $3.75. A case history, covering the development, management, faults, and virtues of the corporation. Chief sources of the information are the reports of a Federal Communications Committee investigation, which, although of public record, have never been published. A large list of references to this material is given.

AIRCRAFT, RADIO, AND ELECTRICAL EQUIPMENT. By H. K. Morgan. New York and Chicago, Pitman Publishing Corporation, 1939. 374 pages, illustrated, 9 by 6 inches, cloth $4.50. The fundamentals of electricity and electrical equipment are presented, present-day equipment is described, and the topics of radio waves, static, direction-finding, ultrahigh frequencies, inspection, and maintenance are discussed. Many schematic diagrams. Questions follow each chapter, with answers grouped in an appendix.

DYADIC CIRCUIT ANALYSIS. By A. Pen-Tung Sah. Scranton, Pa., International Textbook Company, 1939. 415 pages, diagrams, etc., 9 by 5 inches, fabrikoid, $4.50. Based on the work of Gibbs and Wilson, the first four chapters explain the elements of dyadic analysis and the application of these methods to the solution of problems involving three-phase circuits. In the remaining four chapters specific problems, such as transformer banks, transmission lines, and induction and synchronous machines, have been studied from the dyadic viewpoint.

THE ELECTRIC POWER ENGINEERS' HANDBOOK. By W. S. Ibbetson. New York, Chemical Publishing Company; London, E. and F. N. Spon, 1939. 241 pages, illustrated, 9 by 6 inches, cloth, $5.00. This manual for the efficient control and care of all kinds of electrical machinery presents basic theory, description, and directions for the proper operation and maintenance of motors, generators, converters, and rectifiers. There are two chapters on faults, breakdowns, and testing.

THE MATHEMATICAL THEORY OF HUYGENS' PRINCIPLE. By B. B. Baker and E. T. Copson. Oxford, England, Clarendon Press; New York, Oxford University Press, 1939. 124 pages, diagrams, etc., 10 by 7 inches, cloth, $4.25. Deals with the mathematical theory of Huygens' principle in the propagation of light and of sound waves of small amplitude. It is concerned with the general theory of the solution of the partial differential equations governing these phenomena, detailed application of the theory to the solution of special diffraction problems being discussed only as an illustrative example.

ORGANIZATION AND MANAGEMENT OF PRODUCTION. By W. N. Mitchell. New York and London, McGraw-Hill Book Company, 1939. 417 pages, diagrams, etc., 9½ by 6 inches, cloth, $4.00. The growth of attempts to develop an introductory course in production management for business students in colleges, this book deals with factors in the economic, technological, and geographical environment that determine the general forms of organization of production activities. Also discusses problems encountered in administration work. Reference lists, questions, and exercises.

STATIC AND DYNAMIC ELECTRICITY. By W. R. Smythe. New York and London, McGraw-Hill Book Company, 1939. 560 pages, diagrams, etc., 9½ by 6 inches, cloth, $6.00. Formulates the basic laws of electrostatics, magnetostatics, and electromagnetic theory, by concise vector methods, from the underlying experimental facts. It gives an extended treatment of the mathematical technique for applying these laws to specific problems. Although the theory is completely developed from basic experimental facts, the emphasis is on problems, of which there are several hundred. References are given for additional study.

POWER ECONOMICS FOR ENGINEERING STUDENTS. By R. C. Gorham. Pittsburgh, Pa., Pittsburgh Printing Company, 1939. 310 pages, diagrams, etc., 9½ by 6 inches, cloth, $3.25. Part A presents fundamental concepts and factual information, with general principles applicable to engineering practices for best over-all economy. Part B demonstrates the application of these principles through the use of examples, largely from public-utility practice. References and problems.

THE PAGEANT OF ELECTRICITY. By A. P. Morgan. New York and London, D. Appleton-Century Company, 1939. 363 pages, illustrated, 9 by 6 inches, cloth, $3.50. This history of the development of electrical science is a narrative of the lives and achievements of the outstanding personalities who contributed to its progress. Technical matters are treated simply. A chronology of important dates is included.

PRACTICAL ELECTRICAL WIRING. By H. P. Richter. New York and London, McGraw-Hill Book Company, 1939. 503 pages, illustrated, 8½ by 5½ inches, cloth, $3.00. Explains in plain language for the man who does the work all kinds of light and power wiring for home, farm, and factory. All material is based on the National Electrical Code, and selected tables of data from the code are included.

PRINCIPLES OF INDUSTRIAL ORGANIZATION. By D. S. Kimball and D. S. Kimball, Jr. Fifth edition. New York and London, McGraw-Hill Book Company, 1939. 478 pages, illustrated, 9 by 6 inches, cloth, $4.00. Covers internal organization and procedures of industrial enterprises regarding industry in relation to economic organization in general. New material on effect of recent Federal legislation upon industry has been included in this edition, and all statistical data have been revised.

PRODUCTION MANAGEMENT. By A. M. Simons, reviewed by H. F. Dutton. Chicago, American Technical Society, 1940. 588 pages, illustrated, 9 by 6 inches, cloth, $3.50. Aims to provide a practical approach to the problems of plant location, factory layout, work routing, task fixing, office organization, etc., and to the many phases of hiring, training, and handling of the personnel.

PUBLIC SPEAKING FOR TECHNICAL MEN. By S. M. Tucker. New York and London, McGraw-Hill Book Company, 1939. 397 pages, 8 by 6 inches, cloth, $3.00. Virtues and defects in speaking are brought out through narrative treatment, and working principles to be drawn from these examples are summarized at the end of chapters. Covers diction, organization of material, and platform technique, and includes helps for the technical speaker on using charts, answering questions, and meeting other problems.

THE RADIO AMATEUR'S HANDBOOK. Seventeenth edition, 1940. West Hartford, Conn., American Radio Relay League, 1939. 575 pages, illustrated, 10 by 7 inches, paper, $1.00 in U. S. A., $1.25 in foreign countries; bound, $2.50. Covers comprehensively the amateur short-wave field. The fundamental principles and the design, construction, and operation of transmitting and receiving apparatus are described in detail, including ultrahigh-frequency, emergency, and portable equipment. In addition to revision and new illustrations the subject matter in this edition has been divided into major sections with more extensive subdivision than before.

TRANSPORTATION IN THE UNITED STATES. By T. W. Van Metre. Chicago, Foundation Press, 1939. 403 pages, maps, tables, 9½ by 6 inches, cloth, $3.75. Deals chiefly with railroads, first presenting a history of their development in the United States, with some mention of canals and highways. The second part describes the organization, types of service, and accounting of transportation agencies. The theory and practice of rate-making occupy the third part, and in part IV the regulation of the transportation business is considered. References.

VDI-FORSCHUNGSHEFT 397, July–August, 1939. Ausfluss- und Kraftmessungen an der Beschaufluug einer einstufigen Versuchsturbine in Luftversuchsstand. By W. Hartmann. Berlin, VDI-Verlag, 20 pages, illustrated, 12 by 8 inches, paper, 5 rm. This research report describes the setup, procedure, theoretical basis, and results of tests on discharge and power measurements in the blading of an experimental single-stage turbine. The test data are presented in graphs and tables.

MOTOR DICTIONARY. A Complete Dictionary of Motor Terms in Three Languages. II. English-French-German. Compiled by B. R. Dierfeld. Second enlarged edition. London, Massie Publishing Company; New York, Chemical Publishing Company, 1938. 261 pages, 10 by 6 inches, cloth, $4.00. Phrases as well as words are included in this comprehensive three-language dictionary of motor terms. The present section, part II, is alphabetized by the English words, with the corresponding French and German terms added. The revised edition has been enlarged to cover front-wheel drive, independent wheel suspension, the Diesel engine, solid and gaseous fuels, and many recent improvements and innovations in equipment.

RÉSISTANCE MÉCANIQUE DES CONDUCTEURS AÉRIENS. By P. Dévédec. Brussels, Belgium, Alliance Graphique, 1939. 61 pages, diagrams, etc., 11 by 8 inches, paper, 2.20 Belgas. In this pamphlet on the mechanical strength of aerial conductors the author discusses wires under catenary and parabolic loading, shows how to reduce calculations for cables to those for wires, and describes practical applications and actual conditions to be met.

Institute Activities

Increasing Attendance and Interest Maintained at 1940 Winter Convention

CONTINUING the 1939 policy of an enlarged technical program the 1940 AIEE winter convention, held at New York, N. Y., January 22–26, included 18 technical sessions, one more than last year, and eight technical conferences, an increase of three over last year. A brief session on Tuesday afternoon, January 23, for presentation of the Alfred Noble prize, and the special evening program previously announced, which included presentation of the Hoover and Edison medals and a demonstration lecture, were the only nontechnical sessions. Registered attendance, which totaled 1,626, was slightly above the 1939 figure and the highest since 1924. A varied group of inspection trips and the usual entertainment features were included in the program. Statistics on attendance will be found in the accompanying tabulations.

More than 80 technical papers were presented at the sessions, besides conference papers. Since all technical papers, except a few that were noted on the program as available only in advance-copy form, ultimately will be published in TRANSACTIONS, along with their related discussions, no reports on the technical sessions are published here.

MEDAL PRESENTATIONS

As announced in the January issue, the Alfred Noble prize for 1939 was awarded to C. E. Shannon (A'39), who is the youngest person ever to receive the prize, which is limited to authors under 30 years of age. The award was presented at a special session on January 23.

The Hoover Medal was presented to Gano Dunn and the Edison Medal to Philip Torchio, at the special session Wednesday evening, January 24. Details of the presentations, with the text of the addresses, appear on pages 95–102 of this issue. Following the medal ceremonies was a demonstration lecture on "Nuclear Disintegrations," by Doctor Enrico Fermi, text of which appeared in the February issue, pages 57–8.

ENTERTAINMENT AND INSPECTION TRIPS

The customary dinner-dance and smoker were the chief social events of the convention. Attendance at the smoker reached the record-breaking figure of 466; attendance at the dinner-dance totaled 538. The special program of entertainment for women guests included the annual luncheon and bridge party, as well as trips, broadcasts, and other events.

Eight inspection trips were scheduled throughout the week, and in addition tickets to sponsored broadcasts and other events were made available. Attendance at the trips scheduled by the committee totaled 674; attendance at the broadcasts and other miscellaneous events is estimated at about 1,032. Attendance statistics are shown in accompanying tabulations.

Held as usual during winter-convention week was the annual dinner of Eta Kappa Nu celebrating the award of the society's recognition of outstanding young electrical engineers (see the January issue, page 43). About 175 persons attended the dinner, which was held Monday, January 22.

DIRECTORS AND COMMITTEES MEET

The AIEE board of directors met, as is customary, during the winter convention. The national nominating committee also met in accordance with the Institute's by-laws, to select nominees for election to Institute offices for 1940–41. Reports of both these meetings are given in succeeding pages.

Meetings of the following Institute committees were also held during convention week: automatic stations, communication, d-c electric machinery subcommittee, education, electrical machinery, electrochemistry and electrometallurgy, electronics, Lamme medal, membership, planning and co-ordination, power generation, protective devices, relay subcommittee, safety, standards co-ordinating committee 3 subcommittee on insulation testing, standards co-ordinating committee 4, standards for neutral grounding devices, Student Branches, technical committee on sound-level meters, transformer subcommittee, transportation. Following a now established custom, the committee on Student Branches held a luncheon for Branch counselors attending the convention, which was followed by informal discussion.

Brief reports of some of these meetings follow:

Student Branch Committee. At a luncheon meeting to discuss Branch affairs, held in New York January 25, 50 persons were present, including 4 members of the committee on Student Branches, and representing 38 colleges and several industries that have training courses for college graduates. Chairman R. W. Sorensen announced that the new edition of the guidance pamphlet "The Electrical Engineer" has been written, approval for printing it secured, and plans for distribution prepared.

Considerable discussion of the subject of student papers and suggestions for changes in methods of award and nature of prizes resulted in two motions, both passed by the meeting:

1. That the committee on Student Branches consider favorably a recommendation to the committee on award of Institute prizes of a change in the grading system that would reduce the amount of emphasis placed on "importance to electrical engineering", and of an amendment of the last paragraph of the pamphlet on prize awards as it refers to undergraduate papers only.

2. That the committee on Student Branches be requested to consult with the committee on award of Institute prizes in order to make the time of awarding prizes more flexible for each District and to change the value and nature of the student prize.

Doctor C. F. Scott spoke on the importance of stimulating undergraduates to appreciate the significance of professional recognition to the electrical engineer.

Sections Committee. Meeting in New York January 23, the Sections committee voted to establish two new Sections, South Carolina and El Paso, to add unassigned territory in Maine to the Lynn Section, and to transfer Wood County, W. Va., to the Charleston Section (see "Section" items in this issue). The suggestion that the committee meet on Monday and Tuesday June 24 and 25, during the 1940 summer convention was informally approved. It was suggested that program chairmen of neighboring Sections exchange announcements of

Analysis of Registration at Recent Winter Conventions

District	1937	1938	1939	1940
New York City and foreign (3)	629	767	752	743
Middle Eastern (2)	216	292	404	412
North Eastern (1)	222	252	287	332
Great Lakes (5)	38	74	76	76
Southern (4)	21	11	16	22
Canada (10)	17	14	28	20
South West (7)	12	18	37	10
Pacific (8)	7	5	4	6
North West (9)	1	3	2	3
North Central (6)	2	2	4	2
Totals	1,165	1,438	1,610	1,626

Analysis of Registration at 1940 Winter Convention

Classification	Districts 1	2	3	4	5	6	7	8	9	10	Foreign	Totals
Members	277	360	662	16	67	2	10	5	2	18	2	1,421
Men guests	35	32	33	2	4			1	1			108
Women guests	20	20	46	4	5					2		97
Totals	332	412	741	22	76	2	10	6	3	20	2	1,626

meetings and speakers and that such announcements be sent to District vice-presidents, who should help to co-ordinate schedules for speakers.

In connection with the Section items in ELECTRICAL ENGINEERING, it was suggested that the committee request information from all Sections on such subjects as prize papers, co-ordination with other local engineering societies, sponsorship of Branch activities, membership and transfer techniques, educational courses, rotation of meeting places and formation of subsections, publicity, and local members and local membership dues.

C. R. Beardsley reported on the progress made in drafting the model law for registration of engineers and reiterated the need for a committee on legislation in every Section.

Committee on Electrochemistry and Electrometallurgy. Meeting in New York January 23, the AIEE committee on electrochemistry and electrometallurgy approved plans for a symposium on power and the electrochemical industries, to be held jointly by the AIEE Niagara Frontier Section and the Niagara Falls Section of the Electrochemical Society, at Niagara Falls, N. Y., March 14 (see page 130), and considered the possibility of holding a joint meeting with Philadelphia metallurgical groups in connection with the 1941 winter convention. The committee voted to prepare a progress report for publication in ELECTRICAL ENGINEERING, which should be completed in time to be presented at the 1941 winter convention. A subcommittee was appointed to investigate the effect of overvoltage in large units of electrochemical and electrometallurgical installations, with the aim of developing recommendations for switching devices and standards for installations. Attention was called to the report on "Electric Metal-Melting Furnaces", recently published by the Edison Electric Institute.

Committee on Education. Meeting in New York, January 23, the committee on education, after careful consideration of the returns from questionnaires to Section chairmen on the desirability and possible functions of Section education committees, expressed itself as enthusiastically favoring the establishment of Sections committees or subcommittees on (1) junior activities and education and (2) high-school vocational guidance, the latter to act jointly with Sections of other founder societies whenever possible. The committee voted to have its chairman appoint two subcommittees to assemble material and to work with Sections, one on Section activities in "Junior Sections" (like the ASCE Junior Sections), joint junior societies, co-operative educational plans with industry, and other educational programs; the other on guidance activities.

The committee also authorized the chairman to appoint a subcommittee to secure for regular monthly publication in ELECTRICAL ENGINEERING papers of an educational character. It was agreed information that membership in the subcommittees need not be limited to regularly appointed members of the committee on education. Because of the time needed for these subcommittees to make progress and the conflicting dates of the AIEE and SPEE summer conventions this year, the committee decided to prepare no program for the AIEE 1940 summer convention.

Attendance at Special Features of Recent Winter Conventions

Feature	1938	1939	1940
Total registration	1,438	1,610	1,626
Smoker	1,201	1,264	1,466
Dinner-dance	651	527	538
Inspection trips	1,012	1,167	1,700

Committee on Communication. A meeting of the committee on communication was held in New York during the winter convention to discuss programs for future conventions and to arrange for a report covering a review of the activities in the field of communications since 1933. Suggestions regarding papers that might be presented in the near future were actively discussed. Two subjects of special interest were frequency modulation and velocity modulation. Arrangements have been made for a paper on frequency modulation to be presented at the summer convention and it is planned to follow with other papers, possibly at the next winter convention. The committee is also looking into the possibilities of securing for presentation at some meeting in the near future one or several papers discussing velocity modulation. This subject relates to the technique recently developed for generating and amplifying ultrahigh frequencies of the order of 2,000 megacycles.

Committees on Sound. Following the Conference on Sound of January 23 (see page 128), the technical committee on sound levels and sound-level meters met with the AIEE committee on sound on January 24, R. G. McCurdy presiding. The meeting was for the purpose of discussing proposals for changes and additions to the tentative standards for sound level meters and to consider comments received on the AIEE test code for apparatus noise measurement. Several decisions were reached regarding the tentative standards and it was agreed to submit these decisions to the entire membership of the technical committee for comment before regarding them as final. Several comments suggesting revisions in the test code were discussed and it was agreed that certain revisions would be made and the revised code would then be submitted for comment to interested parties.

CONFERENCES

The eight technical conferences held during the 1940 winter convention were on the following subjects: electric welding, network analysis and synthesis—feedback amplifiers, sound, test code for synchronous machines, transportation, increasing the use of electronic devices, standards, definitions. Brief reports of some of these conferences follow:

Electronic Devices. The technical conference on increasing the use of electronic devices sponsored by the joint committee on electronics, was attended by about 80 persons, representing in about equal number manufacturers of electronic devices, users, and educational institutions. The factor most frequently mentioned as restricting increase in the use of electronic devices is lack of specific information on tube application circuits and modes of operation of apparatus using tubes. Regarded as probably most effective for increasing the use of such devices were a few kinds of applications, each using large numbers of tubes, and the use of detailed technical publicity. (Reported by W. C. White.)

Test Code for Synchronous Machines. The technical conference on the test code for synchronous machines, held January 24, was attended by 30 or more interested individuals, including the members of the electrical machinery subcommittee on synchronous machines. The entire test code was discussed in outline, and some sections in considerable detail. The important sections on short-circuit tests, reactances, and time constants were taken up first. Hectograph copies of a proposed revision prepared by O. E. Shirley were distributed to those present. A conference paper on the "Effect of Sequential Switching on Measurement of Subtransient Reactances in Synchronous Machines" was presented by Frank von Roeschlaub. Preprint copies of this paper are still available at Institute headquarters.

A new section of the test code on the determination of the synchronizing power coefficient, P_r, used in flywheel calculations, was taken up, and prepared discussions presented by Professor Charles Kingsley and R. V. Shepherd. Specific suggestions regarding many sections of the code were next considered, and the discussion brought out points of view which will be very helpful to the subcommittee in their work of revision.

General suggestions worthy of note include one to the effect that all sections should be made as specific as reasonably possible; that where the ASA *C*-50 standards for rotating machinery cover much the same ground as the test code, the code should in general omit definitions, etc., but make specific reference to the standards; and that where useful testing information is given in the standards, it should be quoted outright in the code, so far as it covers the subject. Also, since the test code for polyphase induction machines was published in complete form in 1937 the suggestion was made that, where applicable, sections of the synchronous machine code use the same wording.

Immediately following the technical conference, the subcommittee on synchronous machines held a luncheon meeting, to organize the work of revision. It is hoped that enough progress can be made in the next few months so that the subcommittee can report the test code to the electrical machinery committee by the time of the summer convention.

Definitions. The conference, sponsored by the subcommittee on definitions of the committee on basic sciences, was held on January 25 with attendance of about 20 persons. The report of the subcommittee regarding definitions of group 05 of the final revised report of committee *C*42 was discussed. Chairman M. G. Malti pointed out the importance of framing accurate and consistent definitions of electrical terms and after reviewing the history of the activity of his subcommittee opened the meeting for discussion. It was suggested that the report be sent to a selected group of indi-

viduals interested in the framing of definitions, for review and comment and also that a copy of the report should be sent to each engineering college for comments and suggestions. (Reported by M. G. Malti, chairman, subcommittee on definitions of the committee on basic sciences.)

Sound. The annual open conference on sound sponsored by the standards subcommittee on sound, was held January 23, with P. L. Alger presiding. About 150 were present. Progress in noise and vibration measurements was reported in one formal paper and four conference papers.

Formal paper 40-13—"Harmonic Theory of Noise in Induction Motors" by W. J. Morrill, General Electric Company

Conference paper—"New Information on Sound Levels Existing in Various Locations" by D. F. Seacord, Bell Telephone Laboratories, Inc.

Conference paper—"Sound Level Meter Standards and Tolerances" by J. M. Barstow, Bell Telephone Laboratories, Inc.

Conference paper—"Progress in Vibration Measurement. Shall a Test Code on This Subject Be Developed?" by C. D. Greentree, General Electric Company

Conference paper—"Experiences in Sound Measurements" by E. J. Abbott, Physicists Research Company

W. J. Morrill presented a theory of noise generation particularly adapted to use with small single-phase motors, with attention concentrated on the most probable sources of noise. The theory presented pointed out the various magnetic frequencies that can be expected with various combinations of rotor and stator slots. Mr. Morrill has checked his theory on a large number of motors and has found that good agreement with test results is obtained. The paper was discussed by C. G. Veinott, S. Haar, and others.

D. F. Seacord presented a report supplementing similar data presented at the 1939 conference on sound measurement, and giving the results of sound-level measurements of room noise in 2,200 locations expressed in terms of annual average levels. Values were also given representing the average differences in sound level between summer and winter conditions for various typical types of locations. The annual average sound levels and the range of variation (excluding the five per cent noisiest and the five per cent quietest locations) at three general types of location are as follows:

Type of Location	Annual Average Sound Level (Decibels)	Range Included in 90 Per Cent of Locations (Decibels)
Residence	43	33 to 52
Business	57	43 to 71
Factory	77	57 to 96

These values include the effects of variations in different types of areas ranging from rural to congested city districts. Measurements were also made at the street curb of outdoor noise which is an important contributor to room noise. Average street noise based on data including the range from rural to congested city districts is about 54 decibels at residences and 64 decibels for business locations. The corresponding values including only the congested city districts are 65 decibels for residences and 72 decibels for business locations.

J. M. Barstow discussed tolerances in the responses of sound-level meters and presented some new data on the relation between sound levels and loudness levels, demonstrating the types of noises for which the relations were obtained. It was pointed out that although the standards tolerate certain variations in response over the frequency range for which the weighting is specified, the method of calibrating does not permit the response to be consistently high or low, although within the tolerances, over the whole frequency range. Hence complex noises are more apt to be read as equal by different sound-level meters than are single frequency noises or noises in which the weighted energy lies in a narrow band of frequencies. Results of a questionnaire on proposals to reduce the tolerances below 1,000 cycles were reported. The various factors involved in reduction of tolerances, such as variations in microphone response, variation in electrical meter characteristics, and uncertainties in calibration together with their effects on the cost of manufacturing sound-level meters were discussed, and it was pointed out that as indicated by the results of the questionnaire, tolerances of the order of magnitude of those now incorporated in the standards were necessary. Small sound-level differences of each of four noises were demonstrated for the purpose of giving aural impressions of loudness differences corresponding to variations which might be expected in sound-level meter readings due to tolerances in responses. The new data presented showed the correspondence between sound levels and loudness levels for certain noises. It was recommended that more data of this type be taken, using different types of complex noises, in order that the types of noise for which the relation departs most widely from the average may be noted and examined for characteristics causing the deviation. Such information might lead to modifications in sound-level meter standards which would reduce variations in the relation between sound levels and loudness levels.

C. D. Greentree presented a proposal for the setting up of standards for vibration measurements, suggesting that standards in vibration terminology, methods of measurement, and vibration measuring instruments are needed. In vibration terminology, the word "amplitude" is often misused to indicate displacement. Mr. Greentree pointed out that amplitude can apply quantitatively to either vibration displacement, vibration velocity, or vibration acceleration. Vibration measurements can be made to determine the amplitude of either of these three quantities. In sinusoidal vibrations, if the frequency of vibration and one of the above quantities are known, the other two may be calculated. In complex vibrations, no such simple relationship exists. Hence, for the majority of vibration measurements it is necessary to choose one of these quantities. Mr. Greentree pointed out that the measurement of vibration velocity agreed better with the nuisance value of the vibration based upon its noise producing capabilities than the other two. In frequencies below the audible range, vibration velocity is also in better agreement with the nuisance effect upon the individual based upon discomfort and feeling. He strongly recommended, therefore, that the unit of vibration velocity be generally introduced as a useful method for specifying magnitudes of vibration. He also pointed out that in many cases the vibration standards for the calibration of instruments were inadequate, and concentrated effort should be directed toward the improvement of this condition.

Commenting on Mr. Greentree's talk, Mr. Scott, of the General Radio Company, agreed that vibration velocity measurements were very useful, as an indication of human discomfort with respect to noise and feeling, but pointed out that measurements of displacement and acceleration were also of importance in some applications and should certainly be included. Doctor Fletcher, of the Bell Telephone Laboratories, commented on the mathematical relationships between displacement, velocity, and acceleration for vibrations of various wave shapes. He also suggested that some fundamental work must be done to assure correct definitions and calibration methods in this new field of vibration measurements, just as were necessary at the start of the work on sound standards; so that the AIEE committee should work closely with the ASA group rather than going ahead independently. Mr. Parkinson, of the Johns-Manville Company, was highly in favor of setting up vibration tandards and felt that vibration velocity units should be used in the audible range and also outside the audible range, although others may also be important there.

Mr. Alger then asked for an expression of opinion on the desirability of initiating work on a vibration test code in co-operation with the American Standards Association. It was agreed that this should be done.

V. L. Chrisler, of the Bureau of Standards, commented on his experiences in noise measurements during the past year on fans, stating that differences of 2 to 3 decibels were encountered between measuring instruments caused mainly by differences in over-all acoustic response above 2,000 or 3,000 cycles per second.

Ernest J. Abbott, Physicists Research Company, indicated that altogether too much attention is given to the very academic point of the relation of loudness to sound pressure. We should admit at the outset that sound levels are not loudness, but what of it? The sound levels are none the less useful. From a practical point of view, we can forget about loudness. It is a highly speculative and elusive thing at best. The loudness of ordinary sounds cannot be measured with any known instruments but this is no especial drawback. In fact, it is doubtful if we would find much use for loudness readings even if we could obtain

Future AIEE Meetings

Summer Convention
Swampscott, Mass., June 24–28, 1940

Pacific Coast Convention
Los Angeles, Calif., August 26–30, 1940

Winter Convention
Philadelphia, Pa., January 27–31, 1941

them. Let's quit trying to justify sound level measurements on the basis of loudness, and let us instead recognize the value of sound level on its own account. The sound pressure of a sound is a definite physical quantity which can be measured and which practical experience has proved to be very useful in a wide variety of applications. No excuses are needed to justify the use of sound level readings.

National • • • •

Board of Directors Meets During Winter Convention

At its regular meeting at Institute headquarters, January 23, 1940, the AIEE board of directors approved the following dates and places for meetings:

Annual meeting, 1940, Swampscott, Mass., Monday, June 24. Pacific Coast Convention, 1940, Ambassador Hotel, Los Angeles, Calif., August 26–30 inclusive (selected by convention committee)

Schedule of 1941 conventions and district meetings:

Winter convention, Philadelphia, Pa., January 27–31

Summer convention, Toronto, Can., June 16–20

North Eastern District meeting, Rochester, N. Y., May

Great Lakes District meeting, Fort Wayne, Ind., April

South West District meeting, St. Louis, Mo., date to be determined, not too near other meetings

Dates for the 1941 summer convention, which are a week earlier than usual, were selected to avoid conflicting with the annual meeting of the Society for the Promotion of Engineering Education, to be held at Ann Arbor, Mich., the following week.

Recommendations of the Sections committee for formation of two new Sections, South Carolina and El Paso, and addition of unassigned territory in Maine to the Lynn Section, were approved.

The board approved for printing a revision of AIEE Standard No. 4, "Measurement of Test Voltages in Dielectric Tests", and authorized an appropriation to reprint "The Electrical Engineer", pamphlet to be sold at headquarters for five cents and by mail for ten cents per copy.

Appointments approved by the board were:

Charles LeGeyt Fortescue Fellowship committee

Name	Term Expires
C. A. Powel, chairman	July 31, 1940
D. C. Prince	July 31, 1940
W. F. Davidson	July 31, 1941
W. I. Slichter	July 31, 1941
O. E. Buckley	July 31, 1942
E. S. Lee	July 31, 1942

Appointments by standards committee:

C. H. Sanderson, chairman, sectional committee on definitions of electrical terms (succeeding A. E. Kennelly, deceased)

H. M. Turner, AIEE representative, sectional committee on radio, C16 (succeeding C. H. Sharp, deceased)

Institute representatives, council of American Association for the Advancement of Science:

J. W. Barker	Vannevar Bush

Since the number of papers presented for District prizes is sometimes very small, the pamphlet "National and District Prizes" was amended, upon recommendation of the committee for the award of Institute prizes, to permit consideration for District prizes of papers accumulated over a number of years. The amended paragraph (page 6, January 1937 edition) reads:

"Only papers presented subsequent to the period covered by the last previous award in the class and prior to the end of the last calendar year shall be considered for the prize for best paper and for initial paper. Only papers presented subsequent to the period covered by the last previous award in the class and prior to the end of the last academic (college) year, July 1 to June 30 inclusive, shall be considered for the prize for Branch paper and for graduate student paper."

The board also approved a recommendation from the committee on planning and coordination for the engagement of Science Service to prepare and publicize several AIEE technical-committee reports. The project, which is an experiment for one year only, authorizes reports of progress of the electrical art in the various fields chosen to be written by Science Service for publication in TRANSACTIONS from material supplied by the committees. In addition, popular versions of the reports may be published in *Science News Letter*, supplied to newspapers and other publications by Science Service, and, if of sufficiently broad interest, broadcast by radio.

As a result of a recommendation from Vice-President A. H. Lovell, chairman of the committee on economic status of the engineer, the president was authorized to appoint a committee to investigate conditions under which young engineers are working and to report its findings and recommendations to the board.

The appropriation for American Engineering Council for the year ending September 30, 1940, was increased from $6,000 to $8,333.33.

Other actions included:

Approval of minutes of board of directors meeting, October 27, 1939 and of executive committee meeting, December 11, 1939.

Confirmation of executive committee action, December 27, 1939, on transfer, admission, and Student enrollment as follows:
3 applicants transferred to grade of Fellow; 7 transferred and 4 elected to grade of Member; 47 elected to grade of Associate; 413 Students enrolled.

Approval of reports of board of examiners meetings, December 21, 1939, and January 18, 1940; action on recommendations as follows: 6 applicants transferred to grade of Fellow; 9 transferred and 14 elected to grade of Member; 89 elected to grade of Associate; 96 Students enrolled.

Approval of finance committee reports: expenditures, December, $24,337.33; January, $26,408.86.

Those present were:

President—F. Malcolm Farmer, New York, N. Y.

Past Presidents—W. H. Harrison, John C. Parker, New York, N. Y.

Vice-Presidents—T. F. Barton, New York, N. Y.; F. C. Bolton, College Station, Tex.; Chester L. Dawes, Cambridge, Mass.; L. R. Gamble, Spokane, Wash.; H. W. Hitchcock, Los Angeles, Calif.; A. H. Lovell, Ann Arbor, Mich.; Fred R. Maxwell, Jr., University, Ala.; C. T. Sinclair, Pittsburgh, Pa.; J. M. Thomson, Toronto, Can.; A. L. Turner, Omaha, Nebr.

Directors—C. R. Beardsley, H. S. Osborne, New York, N. Y.; Mark Eldredge, Memphis, Tenn.; R. E. Hellmund, C. A. Powel, East Pittsburgh, Pa.; F. H. Lane, L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; F. J. Meyer, Oklahoma City, Okla.; D. C. Prince, Philadelphia, Pa.; R. W. Sorensen, Pasadena, Calif.

National Treasurer—W. I. Slichter, New York, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

Official Candidates Announced by Nominating Committee

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1940, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, N. Y., January 24, 1940. This committee in accordance with the constitution and bylaws, consists of 15 members, 1 selected by the executive committee of each of the 10 geographical Districts, and 5 selected by the board of directors from its own membership. All of the members of the committee were present, as follows:

C. R. Beardsley, New York, N. Y.; C. L. Dawes, Cambridge, Mass.; Mark Eldredge, Memphis, Tenn.; J. M. Flanigen, Atlanta, Ga.; Fred Garrison, Los Angeles, Calif.; W. B. Hall, Kingston, R. I.; A. S. Langsdorf, St. Louis, Mo.; T. G. LeClair, Chicago, Ill.; A. H. Lovell, Ann Arbor, Mich.; C. A. Powel, East Pittsburgh, Pa.; I. M. Stein, Philadelphia, Pa.; George Sutherland, New York, N. Y.; J. M. Thomson, Toronto, Ont.; A. L. Turner, Omaha, Neb.; H. L. Vincent, Spokane, Wash.; and H. H. Henline, secretary of the committee.

Following is the list of official candidates selected by the committee:

FOR PRESIDENT

R. W. Sorensen, professor and head of the department of electrical engineering, California Institute of Technology, Pasadena, Calif.

FOR VICE-PRESIDENTS

Everett S. Lee, engineer, general engineering laboratory, General Electric Company, Schenectady, N. Y. (North Eastern District, number 1)

J. W. Barker, dean of engineering, Columbia University, New York, N. Y. (New York City District, number 3)

K. L. Hansen, consulting engineer, Harnischfeger Corporation, Milwaukee, Wis. (Great Lakes District, number 5)

J. L. Hamilton, assistant vice-president, Century Electric Company, St. Louis, Mo. (South West District, number 7)

A. LeRoy Taylor, dean, school of mines and engineering, University of Utah, Salt Lake City, Utah. (North West District, number 9)

FOR DIRECTORS

T. F. Barton, assistant district manager and district engineer, General Electric Company, New York, N. Y.

M. S. Coover, professor and head of electrical-engineering department, Iowa State College, Ames, Iowa

R. G. Warner, electrical engineer, United Illuminating Company, New Haven, Conn.

FOR NATIONAL TREASURER

W. I. Slichter, professor of electrical engineering and head of department, Columbia University, New York, N. Y.

The constitution and bylaws of the Institute provide that the nominations made by the committee shall be published in the March issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and bylaws:

CONSTITUTION

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District concerned.

BYLAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than March 25th

of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the Constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) National Nominating Committee
by H. H. Henline, *Secretary*

BIOGRAPHICAL SKETCHES OF NOMINEES

In order that those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been nominated, brief biographical sketches are given in the "Personals" columns of this issue.

1941 Winter Convention to Be Held in Philadelphia

On recommendation of the Philadelphia Section, approved by the board of directors, the 1941 AIEE winter convention will be held in Philadelphia, Pa., January 27–31, 1941. This will be the first time the winter convention has been held outside New York since 1924, when it was also held in Philadelphia. N. E. Funk (A'07, F'34) vice-president in charge of engineering, Philadelphia Electric Company, has been appointed chairman of the general convention committee, now being formed. He was also chairman of the general convention committee for the annual meeting of the American Society of Mechanical Engineers held in Philadelphia December 4–8, 1939.

Section • • • •

El Paso, South Carolina Sections Authorized

Formation of two new Sections of the Institute, bringing the total to 70, was authorized by the board of directors at its meeting, January 23, 1940. The South Carolina Section, has that entire state as its territory. A formal organization meeting was held at Columbia, S. C., March 1. The Section plans to hold two meetings a year until it becomes well established, when the number will be increased. The El Paso Section includes El Paso, Hudspeth, Culberson, Presidio, Jeff Davis, Brewster, Terrell, Pecos, Reeves, Loving, Crane, Winkler, Ward, Ector, Midland, Glasscock, Sterling, Coke, Green, Irion, Reagan, and Upton counties in Texas, and the entire state of New Mexico.

Joint Symposium at Niagara

The Niagara Frontier Section of the AIEE and the Niagara Falls Section of the Electrochemical Society are holding a joint symposium on "Power and the Electrochemical Industry," at Niagara Falls, N. Y., March 14, 1940. Speakers are L. H. Fletemeyer, E. I. du Pont de Nemours and Company, Inc.; C. N. Richardson, Mathieson Alkali Works; R. G. Mansfield, Union Carbide Company, all of Niagara Falls; C. C. Levy, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; William Kelly, president, Buffalo Niagara and Eastern Power Corporation, Buffalo, N. Y.; N. R. Stansel, General Electric Company, Schenectady, N. Y. Sessions will be held in the afternoon and evening, with a dinner at which F. A. Lidbury, president, Oldsbury Electrochemical Company, Niagara Falls, will be toastmaster, and C. L. Dawes, vice-president, North Eastern District, and Colin G. Fink, secretary, Electrochemical Society, will speak.

Prize Paper Contest for Maryland Section Students

All Enrolled Students in the Maryland Section are eligible to submit papers on electrical or closely allied subjects to the Section's first prize paper contest for Students. The first prize is an engraved sterling silver goblet, and the second prize an engraved sterling silver key chain. The contest closes March 15, 1940, and the winning papers will be presented at a special meeting of the Section and Student Branches April 29. Members of the Section are being urged to encourage Students to submit papers.

The following items are contributed by C. A. Faust, Mansfield, Ohio, for the Sections committee

Charleston Section Acquires Wood County

Upon the request of the Charleston Section and with the approval of the Columbus Section, Wood County, W. Va., has been transferred from Columbus to Charleston's territory. Parkersburg, the principal city in the county, is the residence of four Institute members, according to the 1939 yearbook.

Entire State of Maine Now in Lynn Section

Nine previously unassigned counties in Maine—Franklin, Somerset, Aroostook, Piscataquis, Penobscot, Washington, Hancock, Knox, and Waldo—have been added to the Lynn Section's territory, making the entire state of Maine a part of this Section. Eleven members of the Institute resided in this territory when the 1939 yearbook was compiled.

Seattle Has Prize Papers, Technical Committees

Joint prizewinners for papers presented at the last annual "members' papers meeting" of the Seattle Section were H. M. Steen, Seattle Cedar Lumber Manufacturing Company, and C. M. Wolfe, instructor in electrical engineering, University of Washington. Mr. Steen's paper was "A Three-Element Cathode-Ray Oscillograph", and Mr. Wolfe's "The Electrical Dehydration of Crude-Oil Emulsions." The meeting was held December 19, 1939, the date having been changed from February to conform to the changed date for consideration of papers for District and National prizes.

For 14 years the Seattle Section has held a yearly meeting for presentation of papers by its members. It was called the "prize papers meeting" until last year, when the name was changed to avoid emphasis on the idea of a contest. When three or more papers are presented, a first prize of $20 and a second prize of $10 are awarded. Rules for judging papers are the same as for AIEE District and National awards, except that entries need not be first papers. Papers are discussed by the Section while the judges are deciding upon the winners.

Seattle holds a similar meeting each April for presentation of papers by Enrolled Students, awarding the winner his first year's dues as Associate in the AIEE.

Technical committees on electronics and power have been reinstated by the Seattle Section after a year's lapse. In 1936–37 the Section had four such study groups, and the two mentioned were continued in 1937–38. When no group meetings were held last year, the number of inquiries caused the Section to resume the activity.

Policy on Local Members Differs in Lynn and Springfield

By planning its programs well in advance, scheduling several interesting meetings for a season, and conducting an intensive membership drive, the Lynn Section secured 665 local members in 1938–39 and 830 in the preceding year. The annual fee of $1.50 per person provides considerable additional revenue for the Section. Local membership is open to all interested men and women. Payment of the annual fee entitles a local member to participate in all activities and to bring one woman guest or one child to each event. Before commencing the membership drive, a complete program of the Section activities is compiled, and a membership committee representing manufacturing, utility, and other companies is appointed. Advertising is carried in local newspapers and posters are distributed. The committee canvasses all prospects. Each local member receives a copy of the season's program and the Section's annual report. Membership tickets are also sold at the door at various lectures and activities.

To be eligible for local membership in the Springfield Section, a candidate must be at least 18 years of age and interested in the objects of the Section. He must be recommended for membership by some one connected with the Section and give three personal references. Finally, he must be approved by the membership committee and pay the annual dues of $2, or $1 after January 1. A local member receives notices of meetings, may attend all meetings, and may serve on committees, but cannot vote, hold office, or be chairman of a committee. The Section has had local members for over ten years.

Standards • • • Personal • • •

U. S. National Committee of I E C. On January 4, 1940, Doctor E. C. Crittenden, assistant director of the International Bureau of Standards accepted the appointment as president of the United States National Committee of the International Electrotechnical Commission, to succeed Doctor Clayton H. Sharp, who had served in that position for 16 years, and who has now been elected honorary president.

Industrial Lighting. I. A. Yost of the Westinghouse Electric and Manufacturing Company has been appointed representative of the AIEE on the Sectional Committee on Industrial Lighting, *A*-11.

Mining Standardization Correlating Committee. The Institute has just reappointed for a period of two years L. C. Ilsley of the Bureau of Mines experiment station as its representative to serve for a period of two years on the Mining Standardization Correlating Committee.

Evaluation of Insulation in Service. C. A. Powel, chairman of standards co-ordinating committee 3, "Insulation Testing and Co-ordination", has formed a subcommittee under Doctor C. F. Hill of Westinghouse Electric and Manufacturing Company to review standard insulation tests and make a study of methods of evaluating insulation in service.

New Co-ordinating Committees. At the January 12 meeting of the standards committee two new co-ordinating committees were authorized: co-ordinating committee 5 on basic theories and units, and co-ordinating committee 6 on interference, sound, and noise problems. The latter will be under the chairmanship of R. G. McCurdy, Bell Telephone Laboratories, and will supersede the present subcommittee on sound. The other members of the committee will be P. L. Alger, W. F. Davidson, R. D. Evans, and Gordon Thompson.

Radio. Professor H. M. Turner of Yale will succeed Doctor C. H. Sharp as an Institute representative on the Sectional Committee on Radio, *C*16. The other members of the AIEE delegation are W. C. White, General Electric Company, and W. Wilson, Bell Telephone Laboratories.

Classification of Representatives. For years it has been the understanding and policy of the standards committee that Institute representatives serving on standardizing committees act in accordance with their views as engineers and not from the viewpoint of company affiliation. In ASA practice it has become the custom, unless they are otherwise instructed, to classify organization representatives according to payroll affiliation. The standards committee therefore at its January 12 meeting directed that in future all AIEE delegates be classified as "General Interests". Delegates are to be advised of this action and urged to seek the advice of the standards committee where partisan interests conflict.

R. W. Sorensen Nominated for Institute President

Royal Wasson Sorensen (A'07, M'13, F'19), professor and head of the department of electrical engineering, California Institute of Technology, Pasadena, has been nominated for the presidency of the AIEE for the 1940–41 term. Born at Alta Vista, Kans., April 25, 1882, he received the degrees of bachelor of science in electrical engineering in 1905 and electrical engineer in 1928, and the honorary degree of doctor of science in 1938, from the University of Colorado. His professional career began in 1905, when he entered the test department of General Electric Company at Schenectady, N. Y. The following year he was made foreman of the transformer test department and later entered the commercial section of the transformer engineering department. In 1908 he was transferred to the Pittsfield, Mass., transformer works of the company. He was made associate professor of electrical engineering, in charge of the department, at Throop Polytechnic Institute (now California Institute of Technology) in 1910, and promoted to full professor the next year. He has held that position ever since. He has also been engaged in consulting practice in various fields since 1913, and since 1931 has been a member of the board of consulting engineers for the Metropolitan Water District of Southern California. His association with the Institute began as an Enrolled Student in 1904. He has been secretary and chairman of the Los Angeles Section (1919–21), Student Branch counselor at California Institute of Technology (1930–33, 1935–36), secretary and chairman of the District 8 committee on Student activities (1926–27). He is chairman of the committee on Student Branches (1938 to date, member 1927–28, 1936 to date) and is serving or has served on the following other national committees: Edison Medal (1938 to date), membership (1939 to date), planning and co-ordination (1939 to date), education (1924–28, 1934–37, 1939 to date), economic status of the engineer (1936 to date, chairman 1936–38), research (1923–24, 1927–30), instruments and measurements (1927–30), Lamme Medal (1933–36), special committee on Institute activities (1936–37). He was vice-president representing District 8, 1933–35, and is now serving as a director. His paper, "The Economic Status of the Engineer", was awarded the 1938 AIEE national prize for best paper in public relations and education. In addition to his Institute activities he is now serving as a vice-president of the Society for the Promotion of Engineering Education, and is also a member of the Engineers' Council for Professional Development and of Tau Beta Pi and Sigma Xi.

Vice-Presidential Nominees Are Lee, Barker, Hansen, Hamilton, and Taylor

Everett Samuel Lee (A'20, M'28, F'30) engineer in charge of general engineering laboratory, General Electric Company, Schenectady, N. Y., has been nominated to serve the Institute as vice-president, representing the North Eastern District (number 1). He was born at Chicago, Ill., November 19, 1891, and received the degrees of bachelor of science in electrical engineering from the University of Illinois in 1913 and of master of science in electrical engineering from Union College in 1915. From 1913 to 1916 he was an instructor in electrical engineering at Union College and a laboratory assistant at General Electric Company, Schenectady, N. Y. He was with the Locomotive Stoker Company, Chicago, 1916–17, and after a year in charge of machine gunnery at the United States Army School of Military Aeronautics at Urbana, Ill., returned to General Electric in 1918. He has been with the company continuously since that time, becoming assistant engineer of the general engineering laboratory in 1928 and assuming his present position in 1931. He has been a director of the Institute (1933–37) and chairman of the Schenectady Section (1928–29), and has served on the following national committees: executive (1933–37), headquarters (1936–37), Sections (1929–34), meetings and papers (1927–30; now technical program committee), membership (1933–38, chairman 1933–36), finance (1933–37, chairman 1936–37), transfers (1934–36, 1937–39, chairman 1937–39). He represented the Institute on the division of engineering and industrial research of the National Research Council (1936–39). He is at present chairman of the committee on constitution and bylaws (member 1937 to date) and a member of the committees on instruments and measurements (1927 to date), research (1934–36, 1939 to date), Edison Medal (1934–36, 1937 to date), planning and co-ordination (formerly co-ordination of Institute activities, of

R. W. SORENSEN

E. S. LEE

J. W. BARKER

J. L. HAMILTON K. L. HANSEN A. L. TAYLOR T. F. BARTON M. S. COOVER

which he was a member 1930–33, 1936–37), and now and in past years has been active on special committees, and in committee work for other technical societies. He is a member of Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

Joseph Warren Barker (M'26, F'30) dean of engineering, Columbia University, New York, N. Y., has been nominated to serve the Institute as vice-president representing the New York City District (number 3). He was born June 17, 1891, at Lawrence, Mass., and received the degrees of bachelor of science (1916) and master of science (1925) in electrical engineering from Massachusetts Institute of Technology. He served in the Coast Artillery Corps of the United States Army as artillery engineer and adjutant from 1916 to 1925, part of that time as officer in charge of civil affairs of the American forces in Germany. He was appointed associate professor of electrical engineering at Massachusetts Institute of Technology, Cambridge, in 1925, and in 1929 became professor and head of the department of electrical engineering at Lehigh University, Bethlehem, Pa. Since 1930 he has been professor and dean of the faculty of engineering at Columbia University. He is at present chairman of the Institute's technical program committee (member since 1932) and of the committee on award of Institute prizes (member since 1937) and a member of the committees on publication (1934 to date), Edison Medal (1938 to date), education (1930 to date, chairman 1937–39), and planning and co-ordination. He has also served on the committee on production and application of light (1929–39, chairman 1933–35). He represents the Institute on the Iwadare Foundation (1936 to date) and on the United States national committee of the International Electrotechnical Commission. He is a past president of the Illuminating Engineering Society and a member of The American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, Society for the Promotion of Engineering Education, Tau Beta Pi, and Sigma Xi, and has been active in the division of engineering and industrial research, National Research Council.

Klaus Lobeck Hansen (A'17, F'34) consulting engineer, Harnischfeger Corporation, Milwaukee, Wis., has been nominated to serve the Institute as vice-president representing the Great Lakes District (number 5). He was born in Sandefjord, Norway, September 14, 1882, and came to the United States in 1901. He was employed by the National Stamping Works, and the Western Electric Company, both at Chicago, Ill., before entering the University of Illinois where he studied electrical engineering 1903–05. After several months with the Chicago Edison Company, he was employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1906 and continued with the company until 1919, his last position being designing engineer on d-c apparatus. In 1919 he went with the Mechanical Appliance Company (later the Louis Allis Company), Milwaukee, as designing engineer later becoming chief engineer. He left the company in 1921 to engage in consulting and development work on his own patents. He invented the Hansen arc welder, and in its manufacture and sale was associated with the Northwestern Manufacturing Company, Milwaukee, from 1924 to 1932, when it was taken over by the Harnischfeger Corporation. He holds patents on various arc-welding processes and joint patents on induction motors, and has published a number of technical papers, chiefly concerned with welding. He has been a member of the Institute's electric welding committee 1930 to date (chairman 1932–34), was chairman of the Milwaukee Section 1933–34, and chairman of the 1937 AIEE summer convention committee. He is also a member of the American Welding Society, at present serving as vice-president representing its Middle Western Section.

James Lemmon Hamilton (M'15, F'21) assistant vice-president, Century Electric Company, St. Louis, Mo., has been nominated to serve the Institute as vice-president representing the South West District (number 7). He was born September 24, 1883, at Morrisville, Mo., and received the degree of bachelor of science in electrical engineering from the University of Missouri in 1904. After graduation he went with the Emerson Electrical Manufacturing Company, St. Louis, on electrical and mechanical designing, becoming manager of design and development in 1913. In 1915 he became chief engineer of the Century Electric Company, St. Louis, in charge of all engineering work. He was made a director of the company in 1920, and in 1934 became assistant vice-president, with executive responsibility for engineering, research, standards, and manufacturing. He is a member of the American Society for Testing Materials and the National Electrical Manufacturers Association, and is a member of the Institute's committee on electrical machinery (1926–27, 1932 to date, chairman 1936–38).

Albert LeRoy Taylor (M'28) dean of the school of mines and engineering and head of the electrical-engineering department, University of Utah, Salt Lake City, has been nominated to serve the Institute as vice-president representing the North West District (number 9). He was born May 14, 1887, at Logan, Utah, and received the degree of bachelor of science in electrical engineering from the University of Utah in 1907 and that of master of science from the University of Michigan in 1918, and has also done graduate work at Stanford University. He was employed by General Electric Company at Schenectady, N. Y., 1910–11, in the test department and standardizing laboratory. He became an instructor in electrical engineering at the University of Utah in 1911, and except for two years (1912–14) as manager of a contracting firm, and various absences for graduate study, has remained with the University ever since. He was instructor in electrical engineering 1914–18, assistant professor of mechanical engineering, 1918–22, associate professor of mechanical engineering 1922–28, and was made professor and head of the department of electrical engineering in 1929, and dean of the school of mines and engineering in 1939. He has also carried on consulting engineering practice and is the author of a textbook and technical papers. He has been secretary (1931–32) and chairman (1932–33) of the Utah Section and Student Branch counselor (1935–39) and District chairman of Branch counselors (1939). He is also a member of the American Society of Mechanical Engineers, Society for Promotion of Engineering Education, Tau Beta Pi, and Sigma Xi.

Barton, Coover, and Warner Nominated for Institute Directorships

Theophilus Fisk Barton (A'12, M'18, F'30) assistant manager of the New York district, General Electric Company, New York, N. Y., has been nominated to serve as a member of the AIEE board of directors. He

was born December 25, 1885, at Orangeburg, S. C., and studied electrical and mechanical engineering at Clemson Agricultural College, where he received the degree of bachelor of science. In 1906 he entered the testing department of General Electric Company, at Schenectady, N. Y., and in 1909 was transferred to the d-c engineering department. He served in the engineering department of the company's New York office from 1911 to 1917, when he returned to Schenectady as a section head in the central-station-engineering department. He became district engineer of the New York district in 1927, and in 1939 was appointed to his present position. Mr. Barton has twice won Charles A. Coffin Foundation awards for contributions to the electrical industry. He is at present AIEE vice-president representing District 3, and was chairman of the New York Section (1932–33) and chairman of the 1939 winter convention committee. He is a member of the committees on economic status of the engineer (1935 to date), legislation affecting the engineering profession (1931 to date, chairman 1935–37), and industrial power applications, and of the executive and finance committees, and has also served on the membership committee (1917–18), transfers committee (1935–36), board of examiners (1934–37), and on several special committees.

Mervin S. Coover (A'16, M'32) professor and head of the department of electrical engineering, Iowa State College, Ames, has been nominated to serve the Institute as a member of the board of directors. He was born December 9, 1890, at Shippensburg, Pa., and received the degree of electrical engineer at Rensselaer Polytechnic Institute in 1914. The following year he was a student engineer with the New York Central Railroad Company, New York, N. Y. He was engaged in electrical construction work for the Montana Power Company, the Hutchinson (Kans.) Light and Power Company, and the Wilson Grinding Machine Company, Wichita, Kans., until 1918 when he entered the United States Army. In 1919 he became an instructor in electrical engineering at the University of Colorado, Boulder, becoming assistant professor, 1920, associate professor, 1922, and professor, 1930. During the summers he engaged in consultation work for various organizations. He was appointed to his present position at Iowa State College in 1935. He has served the Institute as secretary of the North Central District (1929–33), was a member of the automatic stations committee (1927–29), and is now a member of the committees on Sections (1937 to date), education (1937 to date), and research (1937 to date). He is a director of the Iowa Engineering Society and a member of the Society for Promotion of Engineering Education and Eta Kappa Nu.

Russell Gillette Warner (A'19, M'20) engineer, United Illuminating Company, New Haven, Conn., has been nominated to serve as a member of the Institute's board of directors. Born at New Haven, November 18, 1892, he received the degrees of bachelor of philosophy (1914) and electrical engineer (1920) from Yale University. He was with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., 1914–16, in the student course and later as switchboard engineer. He became an instructor in the department of electrical engineering at Yale University, New Haven, in 1916, and continued in the department as instructor and assistant professor until 1939, when he was appointed engineer in charge of special reorganization work by the United Illuminating Company, New Haven. He was also electrical engineer for the Connecticut Public Utilities Commission 1930–39 and has been consulting engineer for various companies. He has been secretary (1926–31) and chairman (1931–32) of the AIEE Connecticut Section, served on the Institute committees on education (1924–25), electrical machinery (1931–33), and standards (1937–39). He has been secretary of the Connecticut Technical Council since its formation in 1934, and is a member of the Society for Promotion of Engineering Education, Tau Beta Pi, and Sigma Xi.

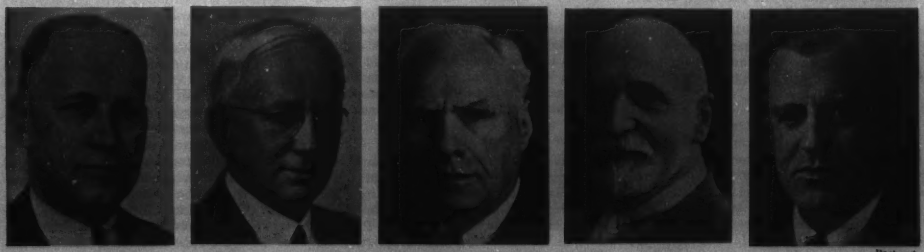
W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12) professor and head of the department of electrical engineering at Columbia University, New York, N. Y., has been renominated to serve as treasurer of the Institute. He has held the position of national treasurer since 1930, and has also served the Institute as a manager (1918–22), vice-president (1922–24), and member of many committees. He is at present a member of five committees and one special committee, and Institute representative on four joint bodies. A biographical sketch of Professor Slichter appeared in the March 1938 issue, page 136.

N. W. Storer to Receive Lamme Medal

Norman Wilson Storer (A'95, F'13) retired consulting railway engineer of the Westinghouse Electric and Manufacturing Company, has been awarded the AIEE Lamme Medal for 1939 "for meritorious achievement in the development of apparatus and machinery for electrical transportation." He was born at Orangeville, Ohio, January 11, 1868, and graduated from Ohio State University with the degree of mechanical engineer in electrical engineering in 1891. In September of that year he entered the employ of the Westinghouse company at East Pittsburgh, Pa., in which he continued without interruption until his retirement in 1936. In 1893 he became assistant to B. G. Lamme (A'03, M'03, Edison Medallist) on the design of d-c machines, especially railway motors. During this period he developed a method of rating railway motors which was later adopted as standard by both the AIEE standards committee and the International Electrotechnical Commission. In 1904 the company's engineering department was reorganized and Mr. Storer was made engineer of the railway division, devoting his entire time to electric transportation. He made notable contributions to the development of both single-phase and high-voltage d-c railway electrificatons, and later had charge of developing electrical equipment for oil electric cars and locomotives. In 1926 he was appointed consulting railway engineer. He has served the Institute as manager (1911–13) and twice as vice-president (1914–16, 1921–23); he has also been Institute representative on the United States national committee of the International Electrotechnical Commission, for which he was advisor on railway motors, and has been active on technical committees, especially the standards and transportation committees. He is the author of many technical papers. In 1933 he was awarded the Lamme Medal of Ohio State University.

Alex Dow (A'93, F'13, HM'37) has retired as president of the Detroit Edison Company, Detroit, Mich., to become chairman of the



Bachrach

R. G. WARNER | A. C. MARSHALL | N. W. STORER | ALEX DOW | D. M. SIMMONS

company's executive committee. He has been president since 1913. He was born in Glasgow, Scotland, April 12, 1862. Although he received no formal technical education, he holds the honorary degrees of master of engineering (1911) and doctor of engineering (1924) from the University of Michigan, and doctor of science (1935) from the University of Detroit. He came to the United States in 1882, becoming a naturalized citizen in 1895. From 1882 to 1888 he was employed by the Baltimore and Ohio Railroad and the Baltimore and Ohio Telegraph Company, and in 1888 was employed as installation electrician at Chicago, Ill., by the Brush Electric Company, becoming district engineer in the Chicago office in 1889. He took charge of the design and construction of the first public lighting plant of the city of Detroit in 1893, and in 1896 became vice-president and general manager of the Edison Electric Illuminating Company of Detroit, continuing as vice-president of the successor company, the Detroit Edison Company, until 1913, when he became its president. He was engineer member of the Detroit Board of Water Commissioners 1916–21 and 1925–27. He was awarded the AIEE Edison Medal for 1936 for "outstanding leadership in the development of the central-station industry and its service to the public." He is also a member and honorary member of both the American Society of Civil Engineers and American Society of Mechanical Engineers and past president of the latter, charter member and past president of the Detroit Engineering Society, member of the Institution of Electrical Engineers of Great Britain, and honorary life member of the Institution of Mechanical Engineers.

A. C. Marshall (A'14, F'29) has been appointed president of the Detroit Edison Company, Detroit, Mich. He was formerly vice-president and general manager. Born September 12, 1872 at Middletown, Ohio, he received the degree of bachelor of science in electrical engineering from the University of Michigan in 1893. After a short period as assistant electrical inspector for the Michigan Inspection Bureau, Detroit, he was employed as field engineer and electrician by the Public Lighting Commission of the City of Detroit in 1894. In 1899 he became chief engineer of the Rapid Railway System, Detroit. He was employed by the Detroit Edison Company on construction in 1904–05, but left the company to become general manager of the Port Huron, Mich., Light and Power Company. In 1911 he became assistant to the president, Eastern Michigan Edison Company, a subsidiary of Detroit Edison, and in 1912 was appointed vice-president of the latter company. He had been vice-president and general manager of the company since 1921.

D. M. Simmons (A'22, F'28) chief engineer, General Cable Corporation, New York, N. Y., has been made a director of the company. Born in New York, July 29, 1889, he received the degrees of bachelor of arts (1911) and electrical engineer (1913) and the honorary degree of doctor of engineering (1939) from Princeton University. He was employed by the Standard Underground Cable Company in research and engineering work at Pittsburgh, Pa., from 1913 until 1927, when that company joined with others to form the General Cable Corporation. He was made director of high-voltage engineering in the latter company in 1928 and chief consulting engineer in 1930. He holds a number of patents in the United States and other countries and is the author of many technical articles. He is past president of the Insulated Power Cable Engineers Association, and has served the AIEE as chairman of the Pittsburgh Section and member of several committees.

S. E. Schultz (A'25) has been appointed acting chief engineer for the Bonneville project, Portland, Ore. For some months he had been engaged in research and investigation work on the staff on a consulting basis, and before that time was electrical engineer for the Port of New York Authority, New York, N. Y. A native (1899) of Oil City, Pa., he graduated in electrical engineering at Drexel Institute. He was employed as meter tester and later meter superintendent by the Citizens Light and Power Company, Oil City, 1918–20, and as meter tester by the Philadelphia Electric Company, 1920–23. After some months as traffic engineer for the Bell Telephone Company of Pennsylvania, he became distribution engineer for Consumers Power Company, Oil City, in 1924. He was later electrical engineer for Stevens and Wood, and engineer for the Quad Engineering Company, both of New York, N. Y., before becoming assistant electrical engineer for the Port of New York Authority in 1935. He later became electrical engineer. Other recent appointments to the Bonneville staff include **D. L. Campbell** (A'38), formerly superintendent of high lines, City of Seattle (Wash.) Lighting Department, as senior transmission engineer; **R. F. Stevens** (A'36) former electrical engineer, Bonneville project, as senior design engineer; **O. A. DeMuth** (A'23, M'30) formerly associate engineer of the project, as senior system engineer; and **C. C. Long** (A'14, M'20), formerly senior electrical engineer, City of Los Angeles, Calif., Metropolitan Water District, as operations engineer.

Frank Conrad (A'02, F'37) assistant chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the gold medal of the American Institute of the City of New York. The award was made "for his pioneering work in short-wave radio and frequency modulation and for his guiding genius developing the world's first radio broadcasting system". Doctor Conrad was awarded the Edison Medal for 1930 and the AIEE Lamme Medal for 1936, and has received a number of other awards for his achievements. He has been associated with the Westinghouse company since 1890.

W. M. White (M'21) manager and chief engineer of hydraulic department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has been selected as one of the recipients of the "Modern Pioneer" awards of the National Association of Manufacturers. The award recognizes Doctor White's invention of the "Hydraucone" draft tube for hydraulic turbines, which increased power output and efficiency and reduced the cost of excavation for installations.

C. R. Higson (A'21, M'32) formerly superintendent of system distribution, Utah Power and Light Company, Salt Lake City, has been made special consultant on distribution engineering and operation for the entire system. He has been associated with the company since 1912 and had held his former position since 1928. **A. C. Kelm** (A'21, M'37) has been advanced from the position of Salt Lake division superintendent to that of system superintendent. He has been with the company since 1916, at Grace, Idaho, and Salt Lake City.

Vivien Kellems (A'30, M'36) president, Kellems Products, Inc., New York, N. Y., has been chosen by the Soroptimist clubs of New York as the outstanding woman in industry for 1940. Miss Kellems, who organized her own company for the manufacture of cable grips in 1928, is said to be the only woman manufacturer in the electrical industry.

E. M. Meyer (A'27) formerly chief electrical engineer, Porcelain Products, Inc., Parkersburg, W. Va., has been made commercial and industrial engineer for Victor Insulators, Inc., Victor, N. Y. He had been with the former company since 1930.

F. R. Lack (M'37), manager, specialty products division, Western Electric Company, New York, N. Y., has been elected a member of the board of directors of the Institute of Radio Engineers for 1940.

Obituary • • •

James Burke (A'93, M'03, F'13) retired chairman of the board, Burke Electric Company, Erie, Pa., and president of the Edison Pioneers, died January 21, 1940. He was born April 7, 1863, at London, Eng., and educated there, coming to New York in 1888. In 1889 he was employed at the Edison Machine Works, Schenectady, N. Y., in the testing department, and was assigned as assistant to Thomas A. Edison when the latter was at Schenectady. When the company's first student course was organized in 1889, Mr. Burke was the first to sign up for it. Later transferred to the engineering department he continued with the company and its successors, the Edison General Electric Company and General Electric Company, until 1894. During the next four years he was in private consulting practice in New York. In 1898 he became consulting engineer for the Bergmann Elektromotoren and Dynamo Works, Berlin, Germany, and in the same year gave up his consulting practice to become its technical director and chief engineer, a position he held until 1902, when he returned to private practice. In 1904 he formed and became president of the Burke Electric Company. He was president until 1928 and then chairman of the board until 1933, when he retired but continued to maintain an advisory interest in the company. He represented both the

AIEE and the National Electrical Manufacturers Association on the United States national committee of the International Electrotechnical Commission and was president of the Commission in 1935. He was well known as an inventor. He had served on the standards and electrical machinery committees of the AIEE, and was also a member of The American Society of Mechanical Engineers and the American Welding Society and past president of NEMA. He had been president of the Edison Pioneers for three years.

Arlington Pearl Little (A'09, M'14) professor of electrical engineering, Colorado School of Mines, Golden, died December 28, 1939. He was born at Clarenceville, Quebec, Can., December 17, 1879, and received the degrees of bachelor of science in electrical engineering (1901) and electrical engineer (1904) from the University of Vermont. He did graduate work also at George Washington University and Yale University. In 1901 and 1902 he was employed in the electrical department of the New England Telephone and Telegraph Company, Boston, Mass. He began his teaching career as assistant in electrical engineering at the Oklahoma Agricultural and Mechanical College, Stillwater, in 1903, leaving in 1906 to become assistant professor of electrical engineering at the University of Syracuse, Syracuse, N. Y. In 1909 he returned to Oklahoma A. and M. as associate professor of electrical engineering in charge of the electrical-engineering department. He was employed by the Bureau of Standards, Washington, D. C., 1914–18, as assistant physicist and later associate physicist, and 1918–19 was an associate professor at Yale University, New Haven, Conn. He had held his position at Colorado School of Mines since 1919. He was also a member of the Society for the Promotion of Engineering Education and an inventor.

George Albert Scoville (A'05, M'30) vice-president and general manager, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., died January 14, 1940. He was born at Ironton, Mo., December 21, 1876, and studied electrical engineering at Stanford University. From 1898 to 1901 he was employed by Western Electric Company, Chicago, Ill.; from 1903 to 1905 in the testing laboratories of the Edison Electric Company (now Southern California Edison Company, Ltd.), Los Angeles, Calif. He returned to Western Electric for a short time for work on Pacific Coast installations, before becoming associated in 1905 with the Dean Electric Company (later the Garford Manufacturing Company), Elyria, Ohio, for which he was successively installation foreman, sales engineer, Pacific Coast resident engineer, and sales manager. He went with the Stromberg-Carlson Telephone Manufacturing Company in 1916, where he had charge of sales, sales engineering, installation, and advertising. He was a director of the company and also president of the Stromberg-Carlson Telephone Manufacturing Company of Canada, Ltd., president of the Scoville Mercantile Company, Atlanta, Ga., and vice-president of Bludworth, Inc., New York, N. Y. He was also a member of the Society of Automotive Engineers and the Institute of Radio Engineers.

William Henry Reynolds (A'04, M'26) retired, formerly in charge of electrical maintenance and construction, General Electric Company, Erie, Pa., died January 12, 1940. He was born April 10, 1867, at Lawrence, Kans., and received the degree of bachelor of science in electrical engineering from the University of Kansas in 1890. Following graduation he was employed by the Edison General Electric Company, in Denver Colo., and by the Thomson-Houston Company, at Chicago, Ill., both predecessors of General Electric. During 1891–92 he was with the Columbian Moving Sidewalk Company, Chicago, engaged on experimental installations and the following year was electrician for the St. Joseph and Benton Harbor (Mich.) Light and Power Company. He was associated with General Electric in St. Louis, Mo., 1893–96, and with the Missouri Edison Company, St. Louis, and the New Orleans and Western Railway, New Orleans, La., from 1896 to 1900, when he returned to General Electric at New York, N. Y. In 1910–11 he was with Canadian General Electric Company, Toronto, Ont., and in 1911 was transferred to the new plant of General Electric at Erie, Pa., where he continued until his retirement in 1930. He was chairman of the AIEE Erie Section 1935–36.

Paul James Ost (M'23) manager and chief engineer of the Electric Power Bureau, City of San Francisco, Calif., died December 30, 1939. He was born at Topeka, Kans., November 9, 1882, and attended the University of Kansas. In 1901 he was employed by the Atchison, Topeka, and Santa Fé Railway in the signal department, becoming engineering inspector, assistant maintenance engineer, and signal supervisor and assistant signal engineer. From 1907 to 1909 he was signal engineer for the Pacific Electric Railway, Los Angeles, Calif., and in 1909 entered the service of the City of San Francisco as assistant city engineer in charge of electrical work. Later he became chief electrical engineer, and when the Electric Power Bureau was organized he was made manager and chief engineer. He designed the city's fire-alarm system, had charge of engineering and equipment design for the municipal railway, and of the street lighting and municipal power and gas purchases for the city. He also designed and had charge of the power system of the Hetch Hetchy water supply project.

Martin E. Popkin (A'19) industrial consultant, New York, N. Y., died January 29, 1940. He was born at Le Havre, France, November 22, 1891, and studied at the Baron Rothschild Academy, Cairo, Egypt. He was employed on various electrical installations and in the laboratory of the Peram Chemical Corporation, New York, before becoming assistant technical examiner for the United States Department of Labor, New York, in 1917. He was personnel director for the Franklin Baker Company, New York, 1919–21, and industrial engineer for W. L. Churchill, 1921–23. The following year he served as consultant for the Warner Sugar Company, Miranda, Cuba, and from 1924 to 1928 was employed by J. Schoeneman, Inc., Baltimore, Md. Since 1929 he had been in private consulting practice, specializing in industrial design. He was the author of textbooks and technical articles and was also a member of The American Society of Mechanical Engineers.

Alfred Lewis Harrington (A'07), chief electrical engineer, Pittsburgh Plate Glass Company, Pittsburgh, Pa., died November 15, 1939, according to information recently received at Institute headquarters. He was born at Reading, Mass., May 6, 1880, and graduated in electrical engineering at Ohio State University in 1905. Following graduation he was employed by General Electric Company as an erecting engineer at Pittsburgh, Pa. Part of his work for that organization consisted of installing electric motors in one of the plants of the Pittsburgh Plate Glass Company. Later he was electrical superintendent for the Carolina Power and Light Company, Raleigh, N. C., and superintendent of electrical construction for the Phenix Utility Company, Hartsville, S. C. In 1919 he took the position with the Pittsburgh Plate Glass Company which he held until his death.

Joseph Herbert Shannon (M'25) assistant plant engineer, RCA Communications, Inc., New York, N. Y., died January 16, 1940. He was born in Ireland in December 1888, and received his technical education at Faraday House, London. During the period 1910–19 he was engaged in the construction and operation of radio stations in England, Canada, Newfoundland, Africa, and Arabia. He was engaged on power-station design and layout for the General Electric Company, Schenectady, N. Y., 1919–20, and in 1920 went with the Radio Corporation of America, New York, N. Y., as power-station designer. About ten years later he became assistant chief communications engineer for RCA Communications, and later assistant plant engineer.

Floyd S. Doxey (A'26) estimating engineer, Pacific Power and Light Company, Portland, Ore., died January 12, 1940. He was born in Salt Lake City, Utah, April 15, 1900, and received the degree of bachelor of science in electrical engineering at the University of Utah in 1925. After graduation he entered the student test course at General Electric Company, Schenectady, N. Y. He joined the staff of the Pacific Power and Light Company as a draftsman in 1927, becoming engineer in 1936 and estimating engineer in 1939.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on February 21, 1940, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Bellaschi, P. L., development engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Fosdick, E. R., engineer, Federal Power Commission, Washington, D. C.

2 to Grade of Fellow

To Grade of Member

Brown, C. E., engineering checker, Pratt and Whitney Aircraft Company, East Hartford, Conn.

Buell, R. C., sponsor engineer, General Electric Company, Schenectady, N. Y.

Burr, H. B., telephone engineer, Wisconsin Telephone Company, Milwaukee.

Hilborn, D. S., senior staff engineer, Bell Telephone Company of Pennsylvania, Philadelphia.

Hubbard, D. C., chief of research, A. B. Chance Company, Centralia, Mo.

Johanson, E. A., associate electrical engineer, Tennessee Valley Authority, Knoxville, Tenn.

Johnson, F. B., assistant to superintendent, New Orleans Public Service, Inc., New Orleans, La.

Moxey, L. W., 3rd, secretary, Keller-Pike Company, Philadelphia, Pa.

Oklund, A. L., design engineer, Louis Allis Company, Milwaukee, Wis.

Osborn, B. K., assistant professor of electrical engineering, Michigan State College, East Lansing.

Shober, W. M., electrical engineer, Aluminum Company of America, Alcoa, Tenn.

Stoughton, J. B., electrical engineer, Aluminum Company of America, Alcoa, Tenn.

Uhl, H. C., assistant district engineer, General Electric Company, Atlanta, Ga.

Wallis, C. M., assistant professor of electrical engineering, University of Missouri, Columbia.

14 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before March 31, 1940, or May 31, 1940, if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Aaltonen, L. O. T., Narragansett Electric Company, Providence, R. I.

Abbott, S. R., Heald Machine Company, Worcester, Mass.

Black, N. L., Central New York Power Corporation, Syracuse, N. Y.

Chapman, J. H., Public Service Company of New Hampshire, Somersworth.

Comsey, K. W., Hygrade Sylvania Corporation, Salem, Mass.

Dalton, B. J., General Electric Company, Schenectady, N. Y.

Deibert, C. R., Massachusetts Institute of Technology, Cambridge.

Dickison, R. H., Hygrade Sylvania Corporation, Salem, Mass.

Edwards, M. A. (Member), General Electric Company, Schenectady, N. Y.

Francis, J. T., 716 Rockdale Avenue, New Bedford, Mass.

Gervais, W. A., Boston Edison Company, Dorchester, Mass.

Hall, W. H., General Electric Company, Lynn, Mass.

Hokanson, H. T., General Electric Company, Schenectady, N. Y.

Houston, R. K., Brown University, Providence, R. I.

Jackson, F. R., Jr., General Electric Company, Pittsfield, Mass.

Kimball, R. B., General Electric Company, Schenectady, N. Y.

Klumb, R. E., General Electric Company, Schenectady, N. Y.

Kudravetz, M. K., United States War Department, Waterbury, Conn.

Lituchy, N. J., Pratt and Whitney Aircraft, East Hartford, Conn.

Magruder, H. W., General Electric Company, Schenectady, N. Y.

Maun, W. B., General Electric Company, Lynn, Mass.

Markel, M., Markel Electric Products, Inc., Buffalo, N. Y.

Marzullo, A. A., 42 Townsend Avenue, New Haven, Conn.

Mazur, J. G., Yale and Towne Manufacturing Company, Stamford, Conn.

McAteer, L. F., General Electric Company, Pittsfield, Mass.

McCarty, R. W., Eastman Kodak Company, Rochester, N. Y.

McComb, R. D., General Electric Company, Schenectady, N. Y.

Messimer, W. D., American Steel and Wire Co., Worcester, Mass.

Miller, W. E., General Electric Company, Schenectady, N. Y.

Miner, G. L., Builders Iron Foundry, Providence, R. I.

Mitchell, W. C., Jr., General Electric Company, Lynn, Mass.

Norberg, A. V., General Electric Company, Pittsfield, Mass.

Parshall, H. M., Rensselaer Polytechnic Institute, Troy, N. Y.

Persia, P. M., General Railway Signal Company, Holley, N. Y.

Pinkerton, D. C., General Electric Company, Schenectady, N. Y.

Powers, L. F., Central New York Power Corporation, Watertown, N. Y.

Remscheid, E. J. (Member), General Electric Company, Schenectady, N. Y.

Revercomb, H. E., Eastman Kodak Company, Rochester, N. Y.

Reynolds, R. H., Jr., General Electric Company, Schenectady, N. Y.

Rosenberg, S. L., Department of Public Works, Albany, N. Y.

Schwedes, W. H., General Electric Company, Schenectady, N. Y.

Silver, J. O., Lombard Governor Corporation, Ashland, Mass.

Smith, C. H., General Electric Company, Pittsfield, Mass.

Smith, E. P., General Electric Company, Schenectady, N. Y.

Stetson, P. H., 24 Grove Street, Bangor, Maine.

Stuart, R. M., Clapp Instrument Company, Webster, Mass.

Taylor, N. H., Lombard Governor Corporation, Ashland, Mass.

Thiry, W. C., Bethlehem Steel Company, Lackawanna, N. Y.

Uren, D. E., General Electric Company, Schenectady, N. Y.

Uttal, J. A., General Electric Company, Schenectady, N. Y.

Wantzelius, O. G., General Electric Company, Schenectady, N. Y.

West, W. W., Narragansett Electric Company, Providence, R. I.

Wilson, D. G., Sealand Corporation, Bridgeport, Conn.

2. MIDDLE EASTERN

Adams, E. M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Armstrong, H. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Aspinwall, R. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Baird, L. L., General Electric Company, Philadelphia, Pa.

Barnes, R. D., Rural Electrification Administration, Washington, D. C.

Bates, E. L., Philadelphia Electric Company, Philadelphia, Pa.

Bearer, P. J., Gibson Electric Company, Pittsburgh, Pa.

Berrier, T., American Telephone and Telegraph Company, Washington, D. C.

Biebesheimer, W. B., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Carvellas, J. N., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Chapman, J. J., General Electric Company, Philadelphia, Pa.

Clark, J. A., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Coffin, W. R., 1318 Singer Place, Wilkinsburg, Pa.

Collins, R. K., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Coltrane, H. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Davies, S., Hickok Electrical Instrument Company, Cleveland, Ohio.

Day, W. M., Consolidated Gas and Electric Light Company, Baltimore, Md.

DeMerit, M. (Member), West Penn Power Company, Pittsburgh, Pa.

Dodd, C. J., Line Material Company, Zanesville, Ohio.

Donaldson, T., J. P. Manypenny, Philadelphia, Pa.

Dudek, R. C., United Broadcasting Company, Cleveland, Ohio.

Ellis, B. R., Westinghouse Electric and Manufacturing Company, Philadelphia, Pa.

Engel, F. H. (Member), RCA Manufacturing Company, Inc., Washington, D. C.

Ferree, H. M., General Electric Company, Nela Park, Cleveland, Ohio.

Fischer, F. P., Chesapeake and Potomac Telephone Company, Washington, D. C.

Flockencier, W. E., North Electric Manufacturing Company, Galion, Ohio.

Ford, W. B., Jr., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.

Freehafer, C. R. (Member), Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

Gilkeson, R. F., Philadelphia Electric Company, Philadelphia, Pa.

Goldman, A. W., Appalachian Electric Power Company, Cabin Creek, W. Va.

Green, W. M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Gregory, L. W., Westinghouse Electric and Manufacturing Company, Baltimore, Md.

Gulden, W. W., Cincinnati and Suburban Bell Telephone Company, Cincinnati, Ohio.

Haber, E. H., Electric Service Supplies Company, Philadelphia, Pa.

Haimowitz, B., Bethlehem Steel Company, Bethlehem, Pa.

Hanuschak, M., Ohio Edison Company, Youngstown.

Happy, J., Ohio Public Service Company, Port Clinton.

Hayes, E. M., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Hays, F. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Headley, C. B., Westinghouse Lamp Manufacturing Company, Trenton, N. J.

Heine, L. J. (Member), Mack Manufacturing Corporation, Allentown, Pa.

Hembree, H. G., Rural Electrification Administration, Washington, D. C.

Higgins, T. A., Carnegie-Illinois Company, Monongahela, Pa.

Hoßing, F. H., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Holman, F. H., Master Electric Company of Dayton, Cleveland, Ohio.

Houck, H. E. (Member), E. I. du Pont de Nemours and Company, Wilmington, Del.

Hovarka, E., Ohio Bell Telephone Company, Cleveland.

Hyle, S. J., Duquesne Light Company, Pittsburgh, Pa.

Jackson, R., Jr., Philco Corporation, Philadelphia, Pa.

Johnson, H. D., Hygrade Sylvania Corporation, Emporium, Pa.

Kasch, H., General Electric Company, Philadelphia, Pa.

Keck, L. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Kevern, G. M., United States Army Air Corps, Dayton, Ohio.

Kiefer, D. B., Pittsburgh Coke and Iron Company, Neville Island, Pa.

Kleinhofer, B. A., Electric Service Supplies Company, Philadelphia, Pa.

Kolecki, A., Ohio Crankshaft Company, Cleveland, Ohio.

Ludwig, V. A., Ames Baldwin Wyoming Company, Parkersburg, W. Va.

Lyon, S. B., Monitor Controller Company, Baltimore, Md.

MacMillan, L. W., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Maleski, M., Babcock and Wilcox Company, Barberton, Ohio.

Mansfield, R. L., Carnegie Institute of Technology, Pittsburgh, Pa.

Martin, R. E., General Electric Company, Philadelphia, Pa.

McHugh, J. B., General Electric Company, Philadelphia, Pa.

McKendree, J. H., Jr., Pennsylvania Railroad Company, Philadelphia, Pa.

McMahon, R. E., 837 North Broad Street, Woodbury, N. J.

Meeker, W. F., United States Engineers, Cincinnati, Ohio.

Merrill, R. L., The Autocall Company, Shelby, Ohio.

Meyer, W. G., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Meyers, T. E., Wolfe and Adana Manufacturing Company, Baltimore, Md.

Middough, W. V., Laganke Electric Company, Cleveland, Ohio.

Milde, N. H., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Miller, F. L., Jr., General Electric Company, Erie, Pa.

Moore, R. W., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Morris, W. C., Rural Electrification Administration, Washington, D. C.

Mothersead, C. T., Chesapeake and Potomac Telephone Company, Washington, D. C.

Muller, F. A., Glenn L. Martin Company, Baltimore, Md.

Myers, A. S., Jr., Electric Heating Equipment Company, Philadelphia, Pa.

Newcomer, O. H. (Member), Pennsylvania Railroad, Altoona, Pa.

Niemeyer, H. F., Chesapeake and Potomac Telephone Company, Washington, D. C.

Ogram, R. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

O'Neill, H. T., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Pedgarney, J. S., 653½ Mulberry Avenue, Clarksburg, W. Va.

Pehl, M. M., Ohio Brass Company, Mansfield, Ohio.

Perry, C. S., Jr., RCA Manufacturing Company, Inc., Camden, N. J.

Phillips, W. C., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Powell, W. E., 176 Mill St., Athens, Ohio.

Prince, R. W., Jr., 3172 18 Street, N. W., Washington, D. C.

Quinn, J. C., 435 Breck Street, Scranton, Pa.

Quinn, J. M., J. W. Mills Electric Company, Scranton, Pa.

Rader, R. E., Rural Electrification Administration, Washington, D. C.

Reed, O. W. B., Jr., care Jansky and Bailey, Washington, D. C.
Reitz, N. J., Breinigsville R. D. #2, Seipstown, Pa.
Rhodes, M. D., Rochester and Pittsburgh Coal Company, Indiana, Pa.
Robertson, H. C., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Schaffner, G. W., Bradley Company, Washington, D. C.
Schleinkofer, G. N., Bell Telephone Company of Pennsylvania, Philadelphia, Pa.
Shackelford, F. W., General Electric Company, Philadelphia, Pa.
Shafer, M. R., Jr., National Bureau of Standards, Washington, D. C.
Sherron, R. J., Jr., Pan American Airways, Baltimore, Md.
Silvester, W. R., Box 52, Princeton, N. J.
Smith, H. R., Rural Electrification Administration, Washington, D. C.
Smith, L. E., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Spethmann, E. C., General Electric Company, Erie, Pa.
Tepel, G. E., The Austin Company, East Cleveland, Ohio.
Terrel, R. D., 232 North High Street, Columbus, Ohio.
Tibbetts, W. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Tucker, R. J., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Van Sciver, H. D., II, care E. G. Budd Manufacturing Company, Philadelphia, Pa.
Wanamaker, R. L., Lincoln Electric Company, Cleveland, Ohio.
Warshaw, H. D., Drexel Institute of Technology, Philadelphia, Pa.
Westermeyer, P. H., Columbia Engineering Corporation, Cincinnati, Ohio.
Wetzer, W. R., 1724 P Street, N. W., Washington, D. C.
Whitescarver, R. S., Route #2, Grafton, W. Va.
Willett, L. G., Chesapeake and Potomac Telephone Company, Washington, D. C.
Williams, E. M., Pennsylvania State College, State College, Pa.
Winter, A. F., 500 Maxwell Street, Charleston, W. Va.
Winterich, O. C., Westinghouse Electric and Manufacturing Company, Cleveland, Ohio.
Wright, G. L., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Wynn, J. H., Rosenblatt and Hunt, Charleston, W. Va.
Yagelowich, S. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

3. New York City

Agress, M. C., A. W. Franklin Manufacturing Corporation, New York, N. Y.
Anderson, J. J., United States Rubber Company, New York, N. Y.
Andrasko, J. P., New York University, New York, N. Y.
Aronow, S., United States Signal Corps, Fort Monmouth, Oceanport, N. J.
Badgley, R. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Basten, J. D., Kingston, N. Y.
Bateman, E. J., General Electric Company, New York, N. Y.
Bjornson, W. G., Cornell Dubilier Electric Corporation, South Plainfield, N. J.
Bollman, J. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Braida, L., Consolidated Edison Company of New York, Inc., New York, N. Y.
Brazdionis, J., Signal Engineering and Manufacturing Company, New York, N. Y.
Brocks, P., International Telephone and Telegraph Company, New York, N. Y.
Brynes, K., 4715 Carpenter Avenue, New York, N. Y.
Buckles, R. A., Jr., John Wiley and Sons, Inc., New York, N. Y.
Butterweck, H. W., 138-02—135 Avenue, South Ozone Park, N. Y.
DeWitt, H. W. (Member), New York Telephone Company, New York, N. Y.
Erickson, L. E., Westinghouse Electric and Manufacturing Company, Newark, N. J.
Fontana, R. E., 34-20—32 Street, Astoria, Long Island, N. Y.
Frawley, W. P., Bell Telephone Laboratories, Inc., New York, N. Y.
Gorin, L., New York City Board of Transportation, New York, N. Y.
Gove, K. G., Commercial Radio Sound Corporation, New York, N. Y.
Groome, P. E., American Telephone and Telegraph Company, New York, N. Y.
Gruenberg, E., Gruenberg Electric Company, Inc., New York, N. Y.
Halbrook, W. W., Bell Telephone Laboratories, Inc., New York, N. Y.
Hallenbeck, F. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Hecht, B., 60 Hamilton Place, New York, N. Y.
Hubbard, C. G., Arma Corporation, Brooklyn, N. Y.
Huldschiner, G. (Member), 414 West 120 Street, New York, N. Y.
Huse, R. A., Public Service of New Jersey, Kearny Meadows.
Hutchins, S. R., Long Island Lighting Company, Mineola, L. I., N. Y.
Iannarone, R. P., Diehl Manufacturing Company, Elizabethport, N. J.
Jackson, B. A., The Lummus Company, New York, N. Y.
Jackson, J. A., Westchester Lighting Company, Mount Vernon, N. Y.
Jeffords, J. M., International Soundphotos, New York, N. Y.
Jude, G. F., 282 East Gunhill Road, New York, N. Y.
Kang, B. P., General Cable Corporation, Perth Amboy, N. J.
Kenyon, R. W., Electric Storage Battery Company, New York, N. Y.
Korenski, F. J., 358 Pulaski Street, Port Richmond, S. I., N. Y.
Krause, A. J., Aeronautical Radio Company, Roosevelt Field, L. I., N. Y.
Langborgh, H. V., Public Service Electric and Gas Company, Newark, N. J.
Leva, F. L., United States Army Signal Corps, Fort Monmouth, N. J.
Lindblad, C. W., Sperry Gyroscope Company, Inc., Brooklyn, N. Y.
Lovejoy, E. B., Public Service Electric and Gas Company of New Jersey, Irvington.
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Transactions

Preprint of Papers and Discussions Comprising Pages 129-92 of the 1940 Volume

Radio-Frequency High-Voltage Phenomena

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DURING the many years that large amounts of power have been transmitted over long power lines at high voltage, an enormous amount of work has been done on research and development in connection with the high-voltage low-frequency phenomena encountered. In the years that followed, the use of low radio frequencies for communication purposes brought about the need for knowledge of high-voltage phenomena in the region of 100 kilocycles and up to about 200 kilowatts. The men associated with this equipment did a remarkably good job of design on their equipment as may be seen in some of the apparatus still in use, especially in regard to the large antenna insulators used on the long-wave antennas.

When vacuum tubes made the generation of much higher radio frequencies possible, and it was found that the shorter waves transmitted intelligence more efficiently over long distances, the use of large amounts of power for radio transmitters was discontinued, first, because there was no equipment available to produce so much power and, second, because the more efficient propagation of the shorter waves and the more efficient vacuum-tube receiving equipment provided a satisfactory means of communication with lower power. This being the case, very high voltages at radio frequencies faded into the background.

With the progression of the art, equipment capable of handling larger and larger amounts of power up to the ultrahigh radio frequencies has been developed in order to provide an ever better means of communication between the remotest parts of the globe. With the increasing power has come the problem of voltage stress but only in proportion to about the square root of the energy used, hence the high-voltage difficulties have lagged the development considerably until recently. Voltages presently in use in high-powered transmitters are sufficient to cause frequent dielectric breakdowns, but in most cases the problems have been side-stepped by overdesigning, or what was thought to be so, in order that concentrated effort could be put on other more pressing problems and also because there were apparently no tools for accurate measurement of the quantities involved.

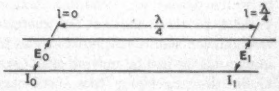
Since the advent of high-power high-frequency transmitters and of simultaneous operation of antennas on several frequencies, the issue of high-voltage radio-frequency phenomena has again come to the foreground. Voltages well over 50,000 root-mean-square volts have been developed in coupled sections[1] under test conditions and in the near future probably several times these values will be common. With the issue of insulation coming to the foreground, a simple and accurate method for high-voltage measurements seems to be a necessity. The basis of such a method has been with the electrical art ever since the development of accurate transmission line equations, the principle of the method lying in the relation between voltage and current separated by a quarter wave length of transmission line. The relation is simply that the voltage on the line at any point is equal to the surge impedance times the current at a point exactly one quarter wave length distant, either toward the receiving or transmitting end assuming no line losses. This relation holds regardless of the line terminations, the only requisite being that the surge impedance of the line over the quarter-wave region be constant.

The relation referred to was described by Steinmetz in 1908 in his "Transient Electric Phenomena and Oscillations". Steinmetz's derivation follows:

Given the general transmission line equations[2]

$$I = A_1\epsilon^{+\alpha l}(\cos \beta l + j \sin \beta l) - A_2\epsilon^{-\alpha l}(\cos \beta l - j \sin \beta l)$$

$$E = \sqrt{\frac{Z}{Y}}\,[A_1\epsilon^{+\alpha l}(\cos \beta l + j \sin \beta l) + A_2\epsilon^{-\alpha l}(\cos \beta l - j \sin \beta l)]$$



For simplification we can assume line losses to be zero and also let $\boldsymbol{E}_0$ be voltage at $l = 0$, the reference point on the line. The $\sqrt{Z/Y}$ becomes $\sqrt{L/C} = z_0$ commonly known as the surge impedance. At the reference point

$$\boldsymbol{I}_0 = (A_1 - A_2)$$

$$\boldsymbol{E}_0 = z_0(A_1 + A_2)$$

At a point $\lambda/4$ distant, $\beta l = \pi/2$ at which point $\boldsymbol{I}_1$ and $\boldsymbol{E}_1$ shall represent the current and voltage

$$\boldsymbol{I}_1 = -j(A_1 + A_2)$$

$$\boldsymbol{E}_1 = -jz_0(A_1 - A_2)$$

From which it follows that

$$\boldsymbol{E}_0 = -jz_0\boldsymbol{I}_1$$

which reduces to $E_0 = z_0 I_1$ when only absolute magnitudes are considered. This simple derivation turns the quarter-wave line into a radio-frequency voltmeter.

Since z_0 occurring in the above relation is usually of the order of 600 ohms, it follows that high voltages and high currents go together. Both may be produced very simply by means of the arrangement shown in figure 1, in which a quarter wave length of line is suspended below an energized transmission line, one end of the quarter-wave line being closed by an adjustable short-circuiting bar. If the section is very loosely coupled to the line, that is, hung a foot or two below the line, the current in the short circuit will be found to be very large since there is only a small amount of resistance present to

Paper 39-123, recommended by the AIEE committee on communication, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26-30, 1939. Manuscript submitted January 16, 1939; made available for preprinting June 5, 1939; released for final publication August 24, 1939.

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1. For all numbered references, see list at end of paper.

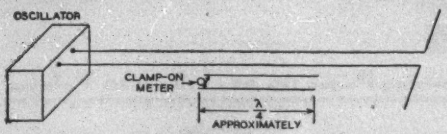

Figure 1. Quarter-wave coupled section on radio-frequency transmission line

stop the flow. As pointed out above, the voltage at the open end of the section, being one quarter wave length away from the large current, will also be large and will be the absolute value of the product of the current by the surge impedance of the section.

Experience has shown that this particular arrangement led to trouble due to the difficulty of insulating the open end of the section. This was eliminated by a much more satisfactory arrangement, shown in figure 2*A*, in which a half-wave section of transmission line short-circuited at both ends and suspended in a plane not parallel to the plane of the energized transmission line is resonated to the frequency on the line by moving one or both of the short-circuiting bars until maximum current flows in the section. An arrangement of this sort may be provided with supports near or beyond the short circuit where the voltage is low, thus presenting no support insulation difficulties. Such a half-wave section may be made, for example, of number 6 copper wire with the upper short-circuiting bar fixed for current measurement and the lower one adjustable for tuning the section, being that the lower short circuit is easily accessible. The current in the fixed short circuit may be measured by a clamp-on meter or much more conveniently by an inductively coupled meter which will be referred to as a "shortometer" and is shown in figure 3. The calibration and theory of this instrument is described in appendix *A*, but it is to be noted here that such a meter reads root-mean-square values, hence all currents or voltages referred to in the following will be root mean square or effective in magnitude.

The power which is required for producing high voltages up to 60,000 volts is very moderate, being of the order of ten kilowatts. The loop resistance of the half-wave section at frequencies of the order of 13 megacycles is around one ohm with number 6 copper wire, so that if all of the line power is diverted into the section, the current developed in the short circuit is approximately equal to the square root of the power in watts, so when the section is dissipating 10,000 watts, the current in the short circuit would be about 100 amperes. With wires of the section spaced 12 inches apart, the surge impedance is 600 ohms, thus the voltage in the center of the half-wave section is about $600 \times 100 = 60{,}000$ volts, which, as a matter of fact, is somewhat higher than the arcing voltage of the clean number 6 wires spaced 12 inches apart. When higher voltages are desired, it is necessary to make the half-wave section of larger diameter wire or of tubing.

The best position of short circuit S_3 in figure 2*A* depends on the geometrical configuration of the transmission line and the half-wave section. When the short circuit S_1 of the section is about a foot below the line and the section is inclined at about

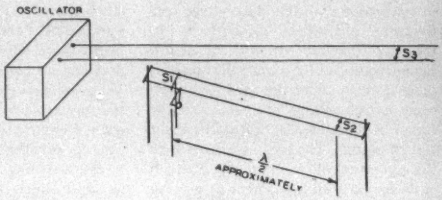

Figure 2A. Half-wave coupled section to transmission line

15 degrees, it is possible to find a position of short circuit S_3 which, when the half-wave section is nearly in tune, reduces the standing waves along the transmission line to reasonable proportions so that the transmitter is able to deliver power. The best position of this short circuit depends on how much additional resistance is introduced into the section by, say, a sample insulator under test placed across the section. Thus short circuit S_3 is made readily adjustable. This short circuit is then used as a kind of mutual-coupling control or adjustable transformer ratio.

High-Voltage Phenomena

The first phenomenon usually encountered with the half-wave section as the movable short circuit approaches the resonant point and the current increases to 25 or 30 amperes is that a flame somewhat similar to a Bunsen-burner flame and about six to eight inches long shoots into space from some point near the middle of the section. Such flames are usually directed upward and blow very easily in the wind to a point of low voltage where they go out. Immediately another flame spurts out from near the center of the section and repeats the process. If the section has considerable slant with respect to the ground, the flames will usually run up the wire even if there is no wind blowing and will go to the low-voltage point unless they strike a projection or sharp point where they will stop moving and will maintain themselves until the power is dropped or the section is detuned. If the wire of the section has a coating of corrosion from the weather, the voltage which the section can stand may be as low as 15,000 or 20,000 volts. This voltage can be doubled or raised even higher before an arc is produced if the wire is made clean and bright by sanding and wiping with a cloth. It is also interesting to note at this point that if the short circuits are taken off and a 60-cycle voltage is applied across the section, the region which has been cleaned shows no corona, while the parts remaining dirty glow with intense and spotty corona.

It is of particular importance to note the striking contrast that exists between 60-cycle phenomenon and 13,000-kilocycle phenomenon in regard to the mechanics of the voltage breakdown of the wires. At 60 cycles as the voltage is gradually increased, first a very faint corona glow develops. As the voltage rises and the corona becomes more intense, streamers shoot out from the wires and finally they become long enough to bridge the gap between the wires terminating in complete breakdown or arc-over. This process is seen to progress in a more or less continuous manner from no

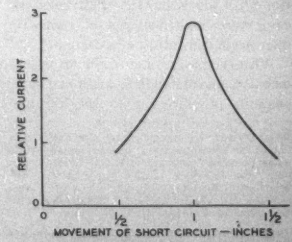

Figure 2B. Approximate half-wave-section tuning response when made of number 6 copper wires spaced 12 inches apart

indication of voltage through gradual steps to complete arc-over between wires. Such is not the case at 13,000 kilocycles. When the voltage on the section is gradually raised, there is no indication of increasing voltage stress preceding the arc into space. As soon as the voltage gets up to a certain critical value, an arc occurs not between wires, but suddenly shoots into space just as if the whole voltage had been instantly applied, there being no noise and no sign of corona accompanying the gradual rise in voltage.

The voltage that a given wire will take at 13,000 kilocycles under the same clean surface conditions varies considerably from day to day apparently depending on atmospheric conditions. Occasionally sections made of clean, smooth number 6 wires spaced 12 inches apart will stand as much as 45,000 volts under the best of atmospheric conditions. One of the strangest phenomena of all is the action of smoke from rubbish or grass fires. Wherever the smoke strikes a high-voltage region of the section, a jagged, crackling spark shoots out, and if the smoke distribution is uniform, the voltage rating of the section will sometimes drop to as low as 20 per cent of the normal rating depending on the concentration of smoke.

The electrostatic field near the midpoint of the half-wave section when a large current is flowing in the short circuits is quite extensive and produces some curious effects, for example, considerable diathermy effect can be felt in one's legs when standing at least four or five feet away. The magnetic field about the short circuit also produces some curious phenomena. If a piece of number 6 wire is fastened onto a wooden handle with iron nails bent around the wire to provide an adjustable short circuit, the nails get red hot while the current in the wire is sufficient to raise the temperature of the latter only a little above atmospheric.

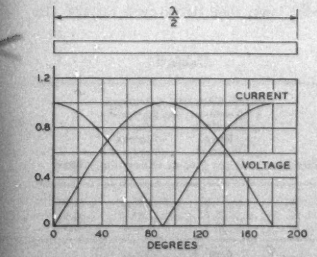

Figure 2C. Current and voltage distribution over a half-wave coupled section

High-Voltage Measurements

The voltage which occurs between the conductors of the half-wave section may be applied across what may be termed "samples under test" such as needle gaps, sphere gaps, insulators, capacitors, etc. These samples are fastened to sections at a distance of one-quarter wave length from the fixed short circuit in which the current is observed. Due to the capacity of the sample the movable short circuit has to be translated toward the fixed short circuit in order that the section may be resonated. The distance through which this short circuit is moved is a very accurate measure of the capacity of the sample and may be used for ascertaining

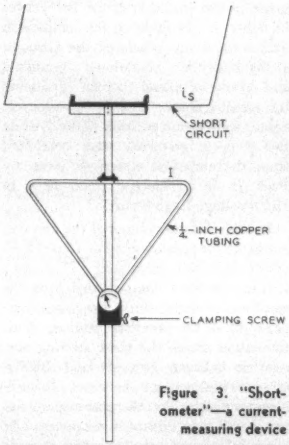

Figure 3. "Shortometer"—a current-measuring device

the capacity of the latter. See appendix *B*.

In order to visualize the more fundamental features of the high-frequency high-voltage phenomena involved, the following arrangements well known to the 60-cycle technique were investigated.

Needle Gaps

In the case of needle gaps the action at 13,000 kilocycles is quite different from that at 60 cycles. Figure 4 shows a curve of the very faintest sign of corona glow with points at 60 cycles in a dark room. On the same sheet are also plotted the voltages at which breakdown occurs at 13,000 kilocycles. In the latter case there is no sign of corona before brilliant white spots, or what may be more descriptively named points fire, suddenly develop at the sharp tips as soon as the gradually rising voltage reaches a certain

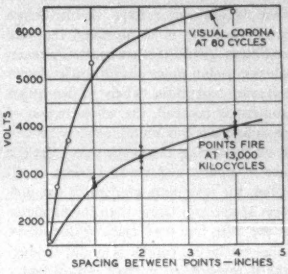

Figure 4. Behavior of needle gaps at 13,000 kilocycles and at 60 cycles

critical value. Considerable energy is immediately dissipated at the points as indicated by the fact that tips are dulled each time a breakdown occurs and also by the fact that the section current drops immediately, showing that a loss or resistance has been introduced into the section. Due to the melting of the points, they can be used only once, after which they have to be sanded, and even then, with the most careful precautions the results are far from being exactly reproducible as shown by the dispersion of points.

Wire Gaps or Parallel Wires

Figure 5 shows the breakdown voltages between wires of various sizes at close spacings in a configuration as shown at the top of the curve sheet. Here again no corona is seen and also no agreement is found between the shape of these curves representing arcing voltage at 13,000 kilocycles and the 60-cycle spark-over voltage as shown in figures 50, 51, and 93 in Peek Jr.'s "Dielectric Phenomena in High Voltage Engineering". However, it is of considerable interest to note that the shape of the 60-cycle corona curves in the same figures is somewhat similar to the curves of figure 5.

Sphere Gaps

Figure 6 shows a curve taken with two-inch spheres set at various spacings. Here for the first time the agreement between 60-cycle spark-over data and 13,000-kilocycle arc-over data is surprisingly good, showing that sphere gaps hold as standards for high-voltage measurements at least up to 13,000 kilocycles when the spacing between the spheres is considerably less than their diameter. As previously there is no sign of corona. In addition the results are surprisingly reproducible.

At 60 cycles, in the case of sphere gaps, when the spacing between the spheres is considerably less than their diameter,

there is also no corona visible before spark-over. It is to be noted that the maximum gradient that exists between spheres under these conditions is almost uniform, and thus, when a disruptive gradient is reached, the whole region of maximum stress is simultaneously broken down producing the spark-over. In the case of points and parallel wires at 60 cycles, the maximum gradient is not uniform at spacings larger than the diameter of the wire but does reach a disruptive value producing corona near the conductors if the applied voltage is sufficiently high. At 13,000 kilocycles such an enormous loss apparently occurs as soon as a disruptive gradient is reached that the ionization is not partial causing corona as at 60 cycles, but is instead complete causing an arc.

This view is further borne out if we consider what Peek Jr. describes as "Disruptive Critical Voltage" and "Disruptive Critical Gradient" on page 188 of the previous citation. Here he shows that corona loss occurs below the voltage which produces visual corona, the voltage and gradient at which corona loss begins being named respectively, "Disruptive Critical Voltage" and "Disruptive Critical Gradient". If the gradients corresponding to voltage applied to the wires as shown in figure 5 are computed from the exact equation for maximum gradient and are plotted as shown in figure 7, a fairly good agreement is found to exist between the 13,000-kilocycle breakdown gradients and the 60-cycle "Disruptive Gradient" values calculated from Peek Jr.'s empirical formula for this gradient shown in table III. Thus again we see that apparently as soon as a voltage is reached which would produce a corona loss at 60 cycles, an arc is produced at 13 megacycles.

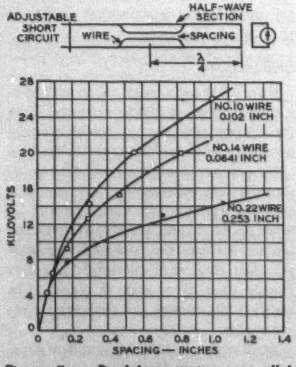

Figure 5. Breakdown tests on parallel wires at 13,000 kilocycles

The "Disruptive Critical Gradient" theory can also be used to explain the action of needle gaps at 13 megacycles. Apparently as soon as the magnitude of the 13-megacycle voltage is equal to the 60-cycle voltage which would cause the first bit of corona loss, the loss at 13 megacycles is so large that points fire is produced, from which it follows that the curve for points fire shown in figure 4 should be below the curve for visible corona at 60 cycles, and this is the case.

It is of interest to note the ratio between the 60-cycle voltage which causes the first signs of visible corona and the 13,000-kilocycle breakdown voltage for needle gaps. In table I are given the ratios of the ordinates of the two curves in figure 4. In table II, for comparison with table I, are tabulated the ratios of 13,000-kilocycle breakdown gradients and 60-cycle visual corona gradients for parallel wires. The 13,000-kilocycle values were obtained from figure 7 while the 60-cycle gradients were computed from the empirical equations given by Peek Jr. in "Dielectric Phenomena in High Voltage Engineering".

In table III are compared the arc-over gradients for parallel wires at 13,000 kilocycles and the calculated "Disruptive Critical Gradient" as obtained from the empirical formula which was taken from page 192 of the previous citation. This tabulation shows the most striking correlation between 60-cycle and 13,000-kilocycle high-voltage phenomena because it seems to show that disruptive gradients are almost independent of frequency. It has been pointed out above that there is apparently no mild dielectric breakdown at 13,000 kilocycles preceding arc-over. Furthermore, since losses are probably proportional to the second power of the frequency, it seems likely that corona cannot exist at such frequencies as 13,000 kilocycles but that complete breakdown of the region must take place as soon as the disruptive gradient is reached.

Variable Air-Capacitor Voltage Ratings

In the light of the fundamental facts presented above, it is now possible to begin to understand the high-voltage high-frequency performance of many of the various pieces of equipment presently in use in modern high-powered radio transmitters, and further, since it is possible to give a reasonably correct diagnosis of the faults of the apparatus, it follows that a basis for a more correct design has also been established.

Table I

Spacing Between Points (Inches)	13,000-Kilocycle Points-Fire Voltages Taken From Figure 4 (Kilovolts)	60-Cycle Corona Voltages From Figure 4 (Kilovolts)	Ratio
0.5	2.1	3.7	0.57
1.0	2.8	5.3	0.53
4.0	4.0	6.4	0.62

Variable air capacitors in high-power transmitters are one of the pieces of equipment which are subjected to rather high radio-frequency voltages, seldom much over 6,000 volts, but nevertheless sufficiently high to produce annoying and troublesome arc-overs at frequent intervals. Whenever such difficulties developed, the usual practice seems to have been to analyze the trouble in the light of 60-cycle phenomena. For example, it

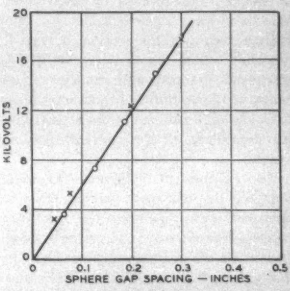

Figure 6. Comparison of sphere-gap performance at 60 cycles and at radio frequencies

Circles—13,000 kilocycles, 2-inch spheres

Crosses—60 cycles, 2⅛-inch spheres

seems to be quite common for manufacturers to list the voltage ratings of variable air capacitors as straight-line functions of the plate spacings both at 60 cycles and at high radio frequencies. The radio-frequency ratings given are somewhat lower than the 60-cycle ratings. In

Table II

Wire Size	13,000-Kilocycle Arc-Over Gradient From Figure 7 (K_v per Cm)	Calculated 60-Cycle Visual Corona Gradient (g_v (Kv per Cm)	Ratio
22	51.3	80.0	0.64
14	38.7	61.0	0.63
10	35.3	54.7	0.65

$g_v = 29.8 \left[1 + \frac{0.30}{\sqrt{\frac{D}{2}}} \right]$ from Peek Jr., page 56.

addition, plate thickness is given some consideration, statements usually being made to the effect that thin plates reduce the maximum voltage ratings by a small amount. It is also sometimes mentioned that the plate shape at the edges has a somewhat marked effect on the rating, square edges tending to produce a lower spark-over voltage.

The 60-cycle ratings are usually correct. Even though the corona which develops during tests is not a straight-line function of voltage, the spark-over voltages vary almost linearly with spacing practically regardless of plate thickness or edge shape. The above data have shown that sphere-gap spark-over voltages agree almost to the point of coincidence, regardless of frequency up to 13 megacycles as shown in figure 6. Figure 4, the curve for 60-cycle corona glow and 13-megacycle points fire, tells an entirely different story. Herein lies the crux to the situation. The 13-megacycle points-fire curve is not at all linear with voltage, but is quite similar to the 60-cycle visible-corona curve for points, and, in addition, as table I shows, is only about 60 per cent of the corona-glow voltage for points.

Naturally, during the life of most capacitors, even though some attempt has been made in the better class of equipment to round off plate edges at least to a small degree, arc-overs occur, leaving small rough spots similar to points. This being the case, a capacitor in service is comprised of smooth plates with varying numbers of little rough spots due to arc-overs on the plate edges. Under these conditions, it is only reasonable to expect that the high radio-frequency voltage rating of such a piece of equipment might be similar to the voltage rating of needle gaps at the same spacing and at the same frequency. When the capacitors are new and reasonably smooth surfaces prevail throughout, it is possible that the voltage rating might follow along the lines of parallel wires which have diameters equal to plate thicknesses since the present common designs simulate a mesh of parallel wires at the plate edges, especially when the plates are in the position of maximum capacity.

Figure 8 gives a rather complete picture of the performance of a number of commercial capacitors after they had been in service for a considerable period of time. Here it is seen that the 60-cycle rating is linear with spacing as claimed by the manufacturers and that voltages well over what might be expected in the highest-powered transmitters can be applied across the capacitor terminals if the frequency of the voltage is in the 60-cycle region. The 13-megacycle high-voltage tests show an entirely different relation between spark-over voltage and plate spacing, the spark-over voltages being much lower than the 60-cycle spark-over ratings, thus explaining the unsatisfactory operation of many supposedly well-designed capacitors.

As is well-known to the 60-cycle technique and as has been pointed out above for 13 megacycles, needle gaps are rather unsatisfactory for voltage measurement compared with sphere gaps since the spark-over voltages are not exactly reproducible, but are more or less dependent on the laws of probability. Since it was pointed out that the capacitors under test were spotted with arc-over marks, it follows that their voltage ratings both at 60 cycles and 13 megacycles should depend to a certain extent on probability, as do needle gaps, hence an exact rating cannot be given, the wide dispersion of points defining regions of limits within which spark-overs will probably occur at various spacings. It is further to be noted on figure 8 that the capacitors tested apparently presented shapes more similar to points than to parallel wires since it is seen that the arc-over voltages for parallel wires having diameters about equal to the plate thicknesses of the capacitors tested were considerably higher.

At present, and at least until further investigation proves otherwise, it seems possible that the high radio-frequency voltage ratings of a variable air capacitor might be obtained from 60-cycle tests.

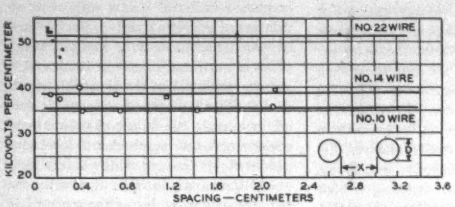

Figure 7 (above). Spark-over gradients for wires at 13,000 kilocycles

Maximum gradient $g = \frac{e}{x} W$ where

$$W = \frac{\frac{x}{D}\sqrt{1+\frac{2D}{x}}}{\cosh^{-1}\left(\frac{x}{D}+1\right)}$$

and e = applied voltage

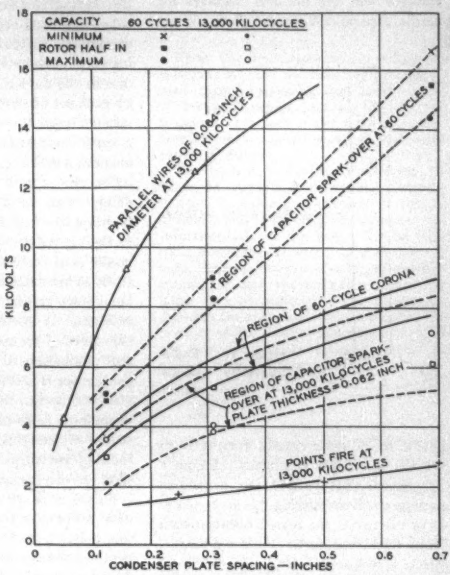
CAPACITY
60 CYCLES
13,000 KILOCYCLES
MINIMUM
ROTOR HALF IN
MAXIMUM
KILOVOLTS
PARALLEL WIRES OF 0.064-INCH DIAMETER AT 13,000 KILOCYCLES
REGION OF CAPACITOR SPARK-OVER AT 60 CYCLES
REGION OF 60-CYCLE CORONA
REGION OF CAPACITOR SPARK-OVER AT 13,000 KILOCYCLES PLATE THICKNESS = 0.062 INCH
POINTS FIRE AT 13,000 KILOCYCLES
CONDENSER PLATE SPACING — INCHES

Figure 8. Spark-over voltages of variable air capacitors at 60 cycles and at 13,000 kilocycles

Table III

Wire Size	13,000-Kilocycle Arc-Over Gradients From Figure 7 (Kv per Cm)	Calculated 60-Cycle "Disruptive Critical Gradient" g_d (Kv per Cm)	Ratio
22	51.3	70.7	1.38
14	38.7	41.0	1.06
10	35.8	34.8	0.99

$$g_d = 29.8\left[1+\frac{0.30}{\sqrt{\frac{D}{2}}}\left(1+230\left(\frac{D}{2}\right)^{\frac{1}{2}}\right)\right]$$ from Peek Jr., page 192.

Previously the 60-cycle spark-over ratings have apparently proved to be much in error at high radio frequencies so an entirely different method will have to be used if the same errors are to be avoided. Tables I and II show that the points fire voltages and the arc-over voltages for needle gaps and wires are about 60 per

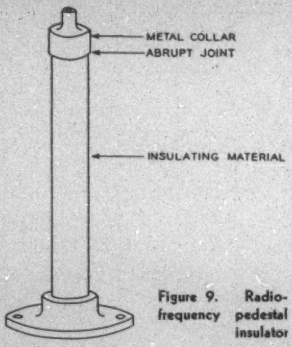

Figure 9. Radio-frequency pedestal insulator

cent of the 60-cycle visual corona voltages for the same test specimens. Figure 8 has shown that variable air capacitors having a given spacing between plates have ratings in the region between such test specimens as needle points and parallel wires, so it is reasonable to believe that a similar fraction of the 60-cycle corona voltage might be taken as the maximum radio-frequency rating of a capacitor. Figure 8 also shows a region for the first signs of 60-cycle visual corona on the group of capacitors used in the tests. However, probably due to irreproducibility of such things as corona glow and needle gap spark-over voltages, the 13-megacycle spark-over voltages are seen to be a little more than 60 per cent of the corona-glow voltages. Where corona first appears on the plates at 60 cycles is not necessarily the point where the 13-megacycle spark-over will occur; nevertheless, the points of 60-cycle and 13-megacycle spark-overs usually coincide, thus substantiating at least a part of the older test methods.

The insulating material used to separate one set of plates from the other in a variable air capacitor provides one point of difference between an exact similarity of capacitors to needle gaps and parallel wires, and therein lies a possible source of error to be carefully avoided. At 60 cycles corona usually develops at the point of contact of the metal plates with this insulating material, the voltage at which this occurs usually having little bearing on the radio-frequency voltage rating. The corona to be observed to obtain the radio-frequency voltage rating is that from the edges of the plates into air.

In the above discussion and presentation of curves it has been pointed out that the radio-frequency voltage rating for sphere gaps and needle points at the same spacing are quite different, the latter being very much lower; the difference being due to the field configurations produced by each set of electrodes. In the case of spheres when the spacing between them is small compared to their diameters, the maximum field or gradient has been shown to be almost uniform, requiring a high voltage with respect to sphere separation to bring the region of maximum stress to the breakdown value. In the case of needle gaps there is no region of uniform stress at reasonable spacings, hence high breakdown gradients are produced at low voltages. It is clear that the radius of curvature of the sphere has all to do with the production of the desired uniform field, hence it is evident that the ultimate goal in capacitor design is the production of uniform fields at regions of maximum stress, which simply means maximum radii of curvature of plate edges rather than increased spacings.

Figure 8 shows that a large improvement could have been made in the capacitors under test if all gradients had been kept as good as that between wires having diameters equal to plate thicknesses. However, it is requisite to use radii of curvatures on the plate edges which are at least one order of magnitude higher than the dimensions of the spots produced by arc-overs, with the hope that the comparatively gradually curving surfaces will partially shield the rough spots produced. The reproducibility of sphere-gap spark-over voltages after repeated spark-overs has proved the validity of such a shielding effect. Not only do the plate edges need larger radii of curvature to reduce high gradients, but also all parts of the apparatus including such things as frame work which are at a high potential with respect to ground or with respect to any object in the near vicinity, if the ultimate in performance is to be achieved.

Insulator Tests

It seems to be common practice at present when manufacturing standoff and strain insulators, to make an abrupt joint between the metal collars and the insulating material as shown in figure 9. If 60-cycle voltages were applied across such insulators, the spark-over voltages would increase almost in proportion to the length of the insulating material. At high radio frequency this is not at all the case, and, in fact, the length has only a small bearing on the matter, the actual rating of the insulator being dependent on such things as the radius of curvature of the cap at the place where it meets the insulating material. As a rule, with insulators of this construction, the material of which the insulator is made is many times better than it need be because it is not the material but the air which breaks down. The damage which occurs is usually not due to the failure of the material under stress, but merely due to local heat produced by the arc which starts from one of the caps. In order to develop the full strength of the insulating material in practice as well as in test, it is necessary to provide the insulator with some sort of corona shields very familiar to the 60-cycle practice, but at high radio frequencies these corona shields have to be considerably better than they need be at 60 cycles. What is necessary at these frequencies is a corona shield which at 60 cycles would produce spark-over before corona, that is, an almost uniform gradient. Anything short of that results in

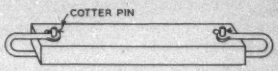

Figure 10. Radio-frequency strain insulator

lower radio-frequency spark-over than at 60 cycles. This point is difficult to overemphasize. If for the sake of illustration we assume an insulator has been provided with shields and that during a 60-cycle test there developed corona at a sharp point along the wires leading to the insulator, perhaps three feet away from opposite terminals, it is safe to predict that at high radio frequencies a breakdown will take place at the previous corona point, and this may happen in spite of the fact that the spacing between the corona shields may be only one-half inch. In order to emphasize this point still further, it might be well to point out the effect of a sharp point in some apparatus of a common type. Quite frequently rectangular strain insulators similar to the one shown in figure 10 are used as part of antenna equipment. These insulators have shackles and pins as fastening members, the pins being provided with cotter pins to insure the permanency of the arrangement. When used in the normal way, the voltage rating at 13 megacycles is only about 18,000 volts because the sharp points of the cotter pins produce arcs into space. If the cotter pins are removed the voltage can be in-

creased to over 40,000 volts and still nothing happens.

In testing insulators it is well to keep in mind that so-called insulator failures occur for two entirely different reasons; (1) breakdown of the air around the metal fittings where the metal comes in contact with the insulating material; (2) breakdown of the insulating material itself. Most of the insulators in use at the present time fail for the first reason. Only a few equipped with carefully designed corona shields or means for distributing the gradient equally over the length of the insulator breakdown for the second reason. The only exception to the latter case consists of insulators of the standoff type which are provided with metal screws that go a long way into the insulating material, thus producing an enormous concentration of flux in the material.

Insulating materials such as synthetic resins prove to be unsatisfactory at high-radio-frequency high voltages. When 1,000 or 2,000 volts at 13 megacycles is applied across a strip of such material about two inches long, charring streamers start over the surface of the specimen, accompanied by considerable smoke, and as soon as the streamers from opposite sides meet, a short circuit is produced and the test is over.

Conclusion

The results of the above measurements seem to indicate rather definitely that there exists a striking correlation between high-voltage phenomena at high radio frequencies and at 60 cycles. The 60-cycle phenomenon which parallels the high-frequency breakdown most closely seems to be the 60-cycle corona. The gradients at which high-frequency breakdown occurs appear to follow the same laws which are followed by the 60-cycle corona. The values of the gradients at which high-frequency breakdowns take place appear to be systematically equal to about 60 per cent of the gradients at which the 60-cycle visual corona begins and, moreover, appear to be equal at least approximately, to the 60-cycle so-called "Disruptive Gradient", that is, those gradients at which corona losses begin to occur at 60 cycles. Our measurements are too meager to establish the extent and the degree of this correspondence between the 60-cycle disruptive gradient and the high-frequency breakdown gradients. These measurements, however, appear to be sufficiently consistent and appear to cover a sufficient variety of electrode configurations to make it seem very probable that such a one-to-one correspondence does exist. If this is the case, and we believe it is, it is not unreasonable to suppose that in the not too distant future, it will be possible to derive useful 60-cycle information from high-frequency measurements. It is only a matter of minutes to determine the breakdown voltage, and hence, the breakdown gradients between two wires or cables at a high radio frequency. If this breakdown gradient so determined is also the disruptive gradient at 60 cycles and will vary with temperature, humidity, smoke, dust, and other conditions in exactly the same way that the 60-cycle disruptive gradient does, then it would be possible with a relatively simple high-frequency setup to find out what a proposed 60-cycle arrangement will do under given conditions. If the 60-cycle disruptive gradient is really equal to the high-frequency breakdown gradient at all, it is difficult to see why the two gradients would behave differently under varied conditions.

In conclusion it should be added that our experiments were made with frequencies all lying in a relatively narrow band around 13,000 kilocycles. Somewhere below this band there lies a transition region in which corona ceases to exist. Our experiments were made primarily for the purpose of answering certain concrete questions in regard to a particular insulation problem and proper facilities were not readily available for extending this investigation into other frequency regions to make it more inclusive.

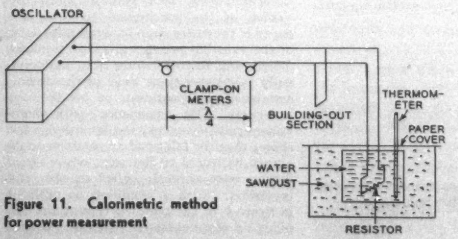

Figure 11. Calorimetric method for power measurement

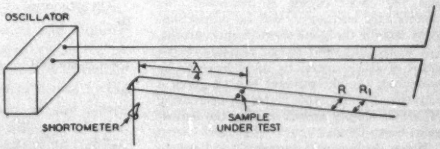

Figure 12. Test setup

Appendix A

Upon the first impression it might be thought that the "shortometer", the much-used current-measuring instrument in all of these tests, would not be independent of frequency, but such is not the case as has been found by experience and may be easily proved as follows:

The current I, in the shortometer, as shown in figure 3, is dependent upon the voltage, E, induced in the loop of the instrument and inversely proportional to the reactance, ωL, of the loop. At the high radio frequencies at which the instrument is used, the impedance is of a higher order of magnitude than the resistance, hence the latter may be neglected. The voltage induced in the instrument loop is equal to the product of the mutual impedance between the loop and the short circuit, times the current, i_s, in the short circuit.

$$I = \frac{\omega M i_s}{\omega L} = \frac{M i_s}{L}$$

in which ω is equal to $2\pi f$ and M is the mutual inductance between the shortometer and the short circuit. Thus, it would seem that the shortometer current is independent of frequency so long as the above quantities predominate.

The accuracy of this whole method is seen to depend entirely upon how accurately the currents involved can be measured. At such high frequencies there is always considerable doubt as to the accuracy of the ammeters used, and, in fact, many of the instrument companies furnish a correction chart for their instruments when used at frequencies above one megacycle. In view of this fact, a calorimetric method was used to standardize two clamp-on meters as shown in figure 11.

The theory of the standardization is as follows:

The line from the transmitter to the dissipating resistor immersed in the water was very carefully balanced so that all of the energy on the line was series current which simply means that the ammeters would read the same regardless of on which side of the line they were placed. This eliminated any possibility of using the transmission line as a single conductor and the resistor as a capacitive by-pass to the line image in the ground. The resistor did

not match the surge impedance of the line, hence, a building-out section was installed in order to make a good balance on the line at the transmitter possible.

The conversion of electrical energy into heat at a known rate in the calorimeter is an accurate and fundamental measure of the power being transmitted by the line. The product of the readings of the clamp-on meters, spaced one-quarter wave apart, when multiplied by the surge impedance of the line is a measure of power also, and this quantity equated to the power delivered to the calorimeter gives a standardization of the meters.

In this particular case the calorimeter and its contents had a heat capacity of 12,700 calories per degree centigrade as measured by weighing the various constituents which absorbed heat and also taking into account their specific heats. The temperature rise as noted over a ten minute period by a very accurate thermometer was 19 degrees centigrade or 1.9 degrees centigrade in one minute. This gave a value of $1.9 \times 12{,}700/60 = 403$ calories per second which is equal to 1,690 watts when multiplied by 4.185, the conversion factor for heat into work. The line ammeters read 0.77 and 1.00, hence $600 \times 0.77K \times 1.00K = 1{,}690$, $K = 1.915$, where K is the multiplying factor for the meter in order to convert its readings into amperes.

When the standardized ammeter and the shortometer are put on a short circuit at the same time and current is caused to flow in the section, the reading of the shortometer may be adjusted to any desired value by simply moving the instrument up or down the staff after loosening the clamping screw. In this way positions of the instrument on the staff may be marked so that the dial of the shortometer will read directly in amperes as shown by the clamp-on meter, taking its correction factor, K, into consideration. From the above shortometer equation it is seen that if the mutual inductance, M, between the shortometer coil and the short circuit is decreased, the shortometer current, I, will be proportionately less for the same short-circuit current, i_s. Being that short-circuit currents of the order of 100 amperes or more have to be measured, the shortometer can be given a convenient multiplying factor by decreasing M, which simply means moving the instrument down its staff.

When dealing with currents too large to be measured by the clamp-on meters at hand, the shortometer may be further calibrated against itself. For instance, the section current may be adjusted to near full-scale reading for the shortometer by adjusting the transmitter output. At this time the shortometer may be moved down its staff until the original reading is cut in half or any other desired value, thus giving a multiplying factor of two or the inverse of whatever the reading was reduced to. In order to make sure that the shortometer reading changed due only to the movement of the instrument on its staff, a meter may be clamped on the transmission line which usually carries a very small current compared to the section short circuit. By means of this meter and a remote control on the transmitter, the power on the transmission line may be kept constant during the shortometer calibration.

The shortometer may be similarly calibrated to read line currents by comparing it with a standardized ammeter clamped onto the line. Being that the field configuration in this latter case is different from that around a short circuit, the calibrations for measuring short-circuit current will be different from those for line currents. Also, since field configuration and dimensions determine the mutual inductance, M, between the shortometer coil and the circuit in question, the shortometer must always be used in the position in which it was calibrated and in conjunction with a short circuit of the same length as the calibrating short circuit. In other words, the shortometer staff must be provided with a calibration for each field configuration in which the instrument is going to be used.

Appendix B

When any piece of equipment is put across the mid-point of a half-wave section, the capacity which it introduces at that point detunes the section so that it is no longer resonant to the frequency on the transmission line. The section can be again made resonant by moving the adjustable short circuit from the point of original and fundamental section resonant point such as R' in figure 12 to a new location, R. From the length of line RR' the exact capacity of the test specimen can be obtained in the following way: It can be assumed that the capacitive reactance of the test specimen was equal to the capacitive reactance of a short section of open line at the center of the coupled section. Instead of cutting this equivalent length out of the center of the half-wave section in order to decrease the capacity to the original value and thus restore resonance, it is much more convenient to move the adjustable short circuit to the new position, R, the distance RR' being equal to the length of section which had to be cut from the center point.

The reactance of an open section is equal to

$$z = -jz_0 \cot 360° \frac{RR'}{\lambda}$$

or

$$\frac{1}{\omega C} = z_0 \cot 360° \frac{RR'}{\lambda}$$

when only absolute magnitudes are considered and which further reduces to

$$C = \frac{1}{z_0 2\pi f \cot 360° \frac{RR'}{\lambda}}$$

Appendix C

Additional Precautions

During high-voltage measurements it is very important to make certain that the radio frequency is not modulated. This is particularly true when the power of the transmitter is varied by remote control and when most of the power tubes are operated below the point of saturation. In our investigations we found it very convenient to connect the vertical plates of a cathode-ray oscillograph across a few inches of the movable short circuit of the half-wave section, while the horizontal plates were connected, as usual, to the sweep circuit. This, or an equivalent arrangement, should always be employed during such measurements to avoid possible errors which may, under some conditions, amount to some 40 per cent.

Harmonics

When a half-wave section is used in making the high-voltage measurements, the second harmonic may contribute to the current but not to the voltage. The third harmonic and other odd harmonics may contribute to both. If harmonics are suspected it is quite easy to make certain whether they are actually present. This may be done by moving the adjustable short circuit to the half-wave positions for the various harmonics and by measuring the current in the short circuit with a sensitive instrument.

In our measurements the harmonic voltages were negligible, but it is quite likely that under some conditions these voltages may affect the results and for this reason this simple check for harmonics is strongly recommended.

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1. Coupled Networks, **Andrew Alford.** IRE *Proceedings*, 1940.

2. Transient Electric Phenomena and Oscillations (a book), **Steinmetz.** Page 287, equation 17.

Discussion

E. A. Leach (nonmember; General Electric Company, West Lynn, Mass.): A brief discussion of the conclusions given in this paper is presented here to emphasize some of the valuable pointers given on insulator design, and to corroborate from independently taken measures, some of those characteristics of breakdown, on air-dielectric capacitors. Our experience with high-voltage radio-frequency insulator design has shown that the failure of an insulator could always be traced to the point where metal fittings were abruptly ended on the solid insulation. Such a condition as outlined in figure 9 of the paper is typical and the piling up of an excessive potential gradient adjacent to the juncture of metal cap and insulator will create excessive heating of the air and solid insulation at that point. By the addition of a suitable corona shield on the cap end and better yet on both ends, the safe operating voltage of a particular insulator may be improved several hundred per cent, and heating practically eliminated.

Another point that is often overlooked in insulator design is that the air film between metallic parts and a solid insulation is a bad offender. The air film, which is often only a few thousandths of an inch in thickness, may show corona breakdown at very low voltages, indicating that the gradient distribution is very poor at that point. An

easy and effective way to minimize trouble from air film breakdown is to fill the air film space with a Glyptal or other insulating varnish. By so doing, you have automatically improved gradient distribution by the simple expedient of substituting a material with a dielectric constant of 3 or 4 for the air with its K of 1. Improvement of as much as 100 per cent may result from this simple device.

The correlation between 60-cycle phenomena and phenomena at moderately high radio frequencies has been used as a basis of design work here for some time. The analysis and test data given in connection with figure 8 check comparable data accumulated here using an entirely different method of voltage measurement. On small units such as the Cardwell "midway" size and Hammarlund "*MTC*" size and on which much of our test data have been taken, we have found that the 60-cycle corona voltage point and the 60-cycle flashover point come very close together. Furthermore, we have found it satisfactory on these small units to translate our radio-frequency requirements into terms of 60-cycle flashover voltages for purposes of inspection and manufacturing test work. The advantage, of course, lies in the fact that the flashover point can be more easily checked than can the corona-formation point. On large units the spread between the 60-cycle corona point and the 60-cycle flashover point is large and on these the corona point is the determining factor from which the radio-frequency capabilities are figured.

In small units we have found that rounded plates in variable capacitors do very little good at voltages lower than 1,500 peak. Above this voltage, the rounding of plates becomes more and more important and at the same time spacing and plate thickness must be increased. For any given plate thickness there is a reasonable limit of plate spacing beyond which there is little improvement of voltage breakdown characteristics. Each type of capacitor construction seems to present slightly different breakdown characteristics; hence no one set of data will answer exactly as a design standard for all methods of construction.

Andrew Alford and Sidney Pickles: We should like to acknowedge our appreciation of E. A. Leach's discussion of our paper.

It may be of interest at this time while discussing insulators to mention very briefly some observations which we made recently at still higher frequencies, namely at 110 and 94 megacycles. At these ultrahigh frequencies such materials as the best grades of glass and ceramics are no longer excellent insulators in that there is a much greater tendency for the insulating material to heat. For this reason metal fittings play a somewhat lesser part. At these frequencies only such excellent insulating materials as quartz and paraffin behave approximately like the best ceramics at 13 megacycles. The trend toward failures on account of heating already becomes noticeable at 20 megacycles.

The breakdown of air itself seems to occur at approximately the same voltages and behaves apparently according to the same laws. Our quantitative data, however, are not as yet sufficiently complete to be presented at this time.

A New Time Standard

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ASSOCIATE AIEE

RESEARCH by many individuals since the beginning of the century has added two new instruments for time measurement to the generally accepted pendulum clock. All of these are based, of course, on the primary astronomical standard which involves the revolution of the earth on its axis.

The oldest of these secondary time standards, the pendulum clock, has been perfected to such an extent that in the form of the so-called Shortt free pendulum, any error can be discovered only with great difficulty. Consequently, this device has come to be over the past decade the accepted standard for certain important purposes. The time signals which are sent out for use by navigators and scientists are generally derived from free pendulum clocks maintained with utmost care in government laboratories. The time-keeping precision of these clocks is said to be of the order of one part in 30,000,000 or about a second a year.

The next most precise standard, namely, the vibrating quartz crystal which is universally used for the control of radio frequency and also for certain kinds of time service, has a precision which is said to exceed one part in 5,000,000 over a considerable period of time. However, this type of standard, if used for the measurement of time as distinguished from radio frequency, is very expensive and complicated and requires expert supervision. As many as ten or more vacuum tubes are needed to reduce the frequency of the quartz crystal to the standard 50 or 60 cycles of our power systems. Obviously, continuity of service with such a large number of vacuum tubes, each having a limited life, might be somewhat troublesome.

The third time standard in fairly common use has a very special form of tuning fork preferably maintained in vibration by vacuum tubes. Standards of this kind are said to operate with a precision of one part in a million, which would correspond with an error less than one-tenth of a second per day.

The effect of variations in temperature on these time standards may be detrimental and therefore it is customary to maintain them at a very constant temperature. Consequently compensating means are usually provided for the purpose of minimizing temperature effect.

Several years ago the writer, who has been concerned with problems of speed and frequency regulation that are of course based on time measurements, determined to build if possible a more simple form of secondary time standard which would be free from some of the objectionable features of the very accurate devices commonly used. Utilizing the vibrations of a stretched string or wire seemed to offer attractive possibilities. Every one knows that a piano or violin string gives out a fairly constant musical note when set in vibration. It is evident, however, that the note depends on the tension of the wire and that it would be very difficult indeed to provide absolutely constant tension through the usual form of mounting. The very fact that frequent tuning is necessary makes this clear.

The force of gravity as a means of providing tension appeared desirable. Experiments at first took the form of a vertical wire stretched over two bridges and tensioned by a weight. If the distance between the two bridges could be held exact it appeared as though such a wire should have a very constant rate of vibration. The accuracy of this arrangement was only fairly satisfactory for several reasons. These were irregular pressure on the wire over the bridges, absorption of a portion of the vibrating energy by the structure which held the bridges, a tendency of the wire to vibrate in different modes, etc.

Gradually the device evolved into the form of a vertical wire or strip supported rigidly at its upper end and tensioned by a weight at its lower end. This was set into vibration by a force supplied at its central point so that when vibrating it consisted of a single loop with nodes at both ends. Many methods of imparting vibrations were tried but eventually a very simple vacuum-tube coupling was adopted which supplied energy through the medium of a permanent bar magnet

Paper 39-126, recommended by the AIEE committee on automatic stations, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939. Manuscript submitted March 18, 1939; made available for preprinting May 8, 1939; released for final publication September 1, 1939.

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The author gratefully acknowledges close co-operation during a long period of research by his associates of the Warren Telechron Company, especially Charles A. Ellis.

that also constituted loading at the middle point of the stretched wire.

In order to compel vibration in a definite plane the vibrating element at first consisted of a narrow strip of metal which was stiff edgewise, but later it was found that a round wire would vibrate in a plane provided the driving magnet was accurately centered.

There are numerous difficulties in a device of this kind. In the first place, more than one mode of vibration may be established, for the wire can obviously vibrate in sections and it can also vibrate axially. Very soon it was discovered that if there were a fairly close correspondence between the normal rate of axial vibration of the system as a whole, including the weight, and one or more harmonics of the transverse vibration, the performance was wholly unsatisfactory. This meant that it was necessary to avoid certain proportions which involved frequency, length, and loading of the wire. Then it was found that a plain stretched wire or strip mounted in the manner described gave a frequency which increased rather rapidly with the amplitude of vibration so that in order to maintain a definite rate it would be necessary to maintain a very constant amplitude.

The effect of temperature on the vibrating wire arranged in this manner is rather complicated. Variations in length due to this cause need not be troublesome because the wire can be made of a material like Invar which has a nearly constant length over a wide range in temperature, but the effect of temperature on the modulus of elasticity of the vibrating materials is an important factor. A vertical wire tensioned by a weight has elastic stiffness in a transverse direction, that is to say, it behaves somewhat like a beam fixed at both ends vibrating under a load at its middle point. The transverse elastic stiffness has the effect of increasing the frequency of vibration beyond that caused by the tensioning weight. The elastic stiffness at a given temperature varies very rapidly in inverse proportion to the fourth power of the diameter of the wire and in direct proportion to the cube of its length.

Common materials which might be used for this purpose like steel, brass, tungsten, beryllium alloys, etc., become less stiff, that is to say, their modulus of elasticity decreases with increasing temperature. Consequently, vibrating wires made from these materials will have decreasing frequency as the temperature rises. Fortunately there are certain materials, especially nickel-steel alloys having composition very similar to Invar, that grow more stiff with increasing temperature. Vibrating wires made from this kind of material will show an increase in frequency as the temperature rises. The temperature coefficient of the elastic modulus of Invar is especially high, being in the neighborhood of 500 parts per million per degree centigrade. The temperature coefficient of the modulus of elasticity in the opposite direction of some of the other materials mentioned is much less, although still many times greater than the temperature coefficient of the length expansion.

It is possible to control the magnitude of the effect which temperature will have on the frequency for a given kind of material by planning the proportions of length, diameter, and loading of the vibrating wire. The smaller the diameter and the greater the length the less will be the effect of temperature changes which influence the elasticity of the material. For convenient lengths, however, and with reasonable loading within the elastic limit of the material used, there will usually remain frequency variations when there are temperature changes. However, these variations may be made as small as desired if advantage is taken of the opposite sign of the temperature coefficient of the elastic modulus by making the vibrating wire in part of a substance like Invar, having a temperature coefficient which gives greater stiffness with rising temperature and in part of another material like beryllium copper which becomes

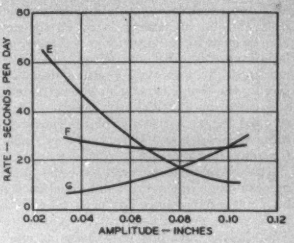


Figure 2. Rate compensation for changes in amplitude by means of a resilient bow

E—Overcompensated—bow length 2.82 inches

F—Full compensated effect—bow length 2.50 inches

G—Undercompensated—bow length 2.27 inches

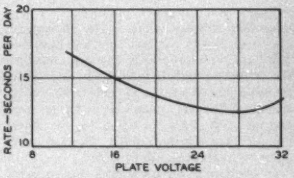
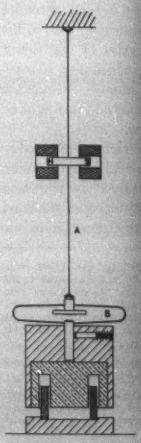


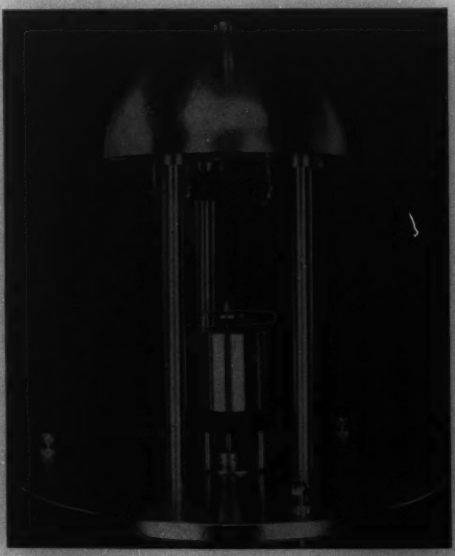
Figure 3. Effect of plate voltage upon time rate

Figure 4. Complete vibrator unit

Diameter of base 14 inches

Figure 1 (below). Diagrammatic representation of vibrator assembly in section





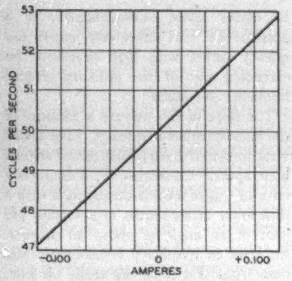


Figure 5. Relation between current in regulating coil and frequency

less stiff with rising temperature. If the relative lengths of these two materials are properly chosen the temperature effect of one may be made to cancel the temperature effect of the other as regards stiffness and if there is a slight residual of length expansion that may also be neutralized by a preponderance of one kind of elastic alteration.

There are alloys like elinvar which have a nearly constant modulus of elasticity with regard to temperature but in the experiments which have been made with this kind of material the reduction of temperature effects has been less satisfactory than by the very simple method of combining materials which have opposite signs of elastic temperature coefficients.

Further means of eliminating any slight residual temperature effect may act by opposing or adding to the gravity force of the weight by an adjustable element such as a weak spring or a thermosensitive magnet which will aid or oppose the tensioning force as the temperature changes.

Variations in rate caused by changes in amplitude can be corrected in a very simple manner. The normal increase in rate with increase in amplitude results because the vibrating wire is comparatively rigid axially so that it forms a connection having a nearly fixed length between the weight and the upper support. The weight has very considerable inertia and it tends to remain at rest in a position where the average force which it exerts on the vibrating wire is constant but the instantaneous force varies. The relationship is obviously slightly different for each amount of amplitude.

The instantaneous effect of the force exerted by the weight results in a component at the center of the vibrating wire tending to restore it to its mid-position and this component of gravity force is proportional to the tangent of the angle of deflection of the vibrating wire. If the component of force which is designated as restoring force were exactly proportional to the displacement of the wire, there would be harmonic motion and isochronism. Then there might be no change in rate with change in amplitude.

However, because of the inertia of the weight and slight axial elasticity of the wire, the instantaneous component of force varies in a different manner, being larger than the tangent of the angle for large angles of deviation and less than the tangent for very small angles. For this reason the frequency rate increases with the amplitude of vibration. In the case of an ordinary clock pendulum the reverse is true. There the rate decreases with increase of amplitude.

It has been found that if an elastic connection be interposed between the weight and the lower end of the vibrating wire, the component of gravity force which tends to restore the wire to its mid-position more nearly approximates proportionality to the tangent of the deflection angle, and if this elastic coupling between the weight and the wire is sufficiently soft the wire will actually vibrate with a slower rate as the amplitude increases.

These facts have resulted in the design of a vibrating element which consists in part of a member that is comparatively stiff in an axial direction corresponding to the wire *A* in figure 1, and another member an elliptic spring *B* which is decidedly elastic in the same direction. The wire, however, is free to vibrate transversely while the spring is comparatively rigid in that direction.

A good result can be obtained by the use of other types of springs. For example, the vibrating wire may consist of an upper portion flexible transversely and stiff axially with the lower portion in the form of a spiral spring which is flexible in both directions. The main desideratum is that the elastic flexibility of the spring member in a vertical direction shall have that scale of stiffness which insures that the frequency rate of transverse vibration of the vertical element will be approximately the same over a reasonable range in amplitude.

While it might be possible to compute the exact dimensions of the elements that are involved in the combination, the problem would be a very complicated one, but it is fairly easy to find the correct proportions by experiment. Figure 2 shows several curves which illustrate the relation between amplitude and rate of a certain vibrating wire when coupled to the tensioning weight by elliptic springs of different lengths. These curves indicate very clearly that with the correct stiffness of elliptical spring the rate of the vibrating wire scarcely changes over a fairly wide range in amplitude.

Various methods of driving the vibrating wire have been tried, all of which involve some form of coupling between the wire and a vacuum-tube circuit. One very satisfactory form consists as shown in figure 1 of a small permanent bar magnet of cobalt steel very rigidly attached at the center of the wire. One end of this magnet projects into a pickup coil and the other end is surrounded by a driving coil. These two coils are connected respectively to one grid and plate of a twin-triode tube.

The other half of the tube is used for amplifying the voltage of the first stage. In order to avoid picking up external frequency in the first stage a $22\frac{1}{2}$-volt plate battery is used. The heater current and the other plate supply voltage come from a regular power circuit. A second tube further amplifies the energy so as to deliver about two watts at 120 volts which is adequate to operate a Telechron clock motor. For greater power a small amount of this output is diverted to another stage of amplification.

The relation between the plate-battery voltage and the time rate in seconds per day is shown in figure 3. The amount of current drawn from the plate battery is less than a tenth of a milliampere so that reduction of battery voltage takes place very slowly indeed. The amount of energy required to keep the string in vibration at ordinary atmospheric pressure is less than half a milliwatt.

The effect on the rate of barometric changes in the atmosphere is extremely small; apparently less than a tenth of a second per day for the ordinary range. Therefore it does not seem necessary for most purposes to provide an air-tight enclosure for this time standard but the instrument is so constructed that a bell jar can be placed over it. The compensation for variations in temperature is so accurate that for most purposes temperature control is unnecessary.

The instrument can be constructed so that 100 degrees Fahrenheit difference in temperature will produce less than one second per day variation in rate. Where the surrounding temperature is not likely to vary more than 10 degrees Fahrenheit the error due to this cause is negligible for many purposes. Probably the best location for an instrument of this kind is on a foundation of its own in an underground enclosure where the temperature would be comparatively constant.

For the purpose of measuring the prog-

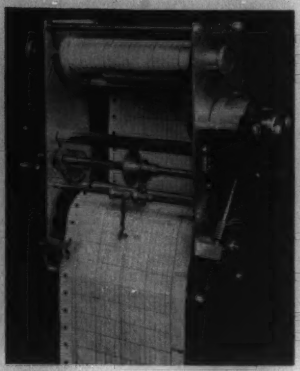


Figure 6. Graphic time comparator

ress which has been made in reducing temperature effects one of these compensated time standards has been exposed to comparatively wide temperature variations for a period of ten days. This was done by subjecting it to rather high room temperature during working hours and then cooling the room at night by shutting off the steam heat and opening the windows to the outside New England air.

The 24-hour average temperature varied from 65 to 81 degrees Fahrenheit and intermediate changes as great as 40 degrees Fahrenheit were observed. Over this period the average rate was one-tenth second per day fast. The greatest error was four-tenths second per day. No attempt has yet been made to determine the extreme precision which can be obtained with this new instrument but the indications are that time can be measured with an error less than one-tenth second per day when favorable conditions are provided.

There is an additional feature of this new time standard which may be of great importance for certain purposes. The weight which tensions the vibrating wire and very definitely controls its frequency is of course constant under the influence of gravity. Forming a part of this weight is a cylindrical Alnico magnet and in the air gap of this magnet there is a coil of fine insulated wire.

When a measured direct current is passed through the coil the reaction between the magnetic flux and this current will produce a force in the same direction as the gravity force but plus or minus in sign depending upon the direction of the current. The value of this current may be accurately adjusted by a graduated potentiometer or resistance so that the frequency rate of the vibrating wire may be controlled with great precision over a moderate range from a distant point. Figure 5 shows the relation between frequency and control current.

The amount of energy necessary to adjust the rate of a 60-cycle time standard over a range of plus or minus one cycle by this magnetic method is less than one-tenth of a watt. Consequently, there are no important heating effects which might be disturbing and the control apparatus may be very simple.

In order to study the performance of these new time standards, an interesting form of graphic comparator illustrated in figure 6 has been constructed. This consists essentially of a long revolving screw arranged transversely with respect to a moving strip chart. The screw is driven through gearing from a Telechron synchronous motor. On the screw there is a nut carrying a gear which is made to rotate by another Telechron motor. The gear reduction from this second motor to the nut is such that the screw and the nut normally revolve at the same speed and in the same direction. Any axial motion of the nut is transmitted to a light slider which carries a pen making contact with the paper chart.

Thus the line drawn by the pen indicates the axial position of the nut at any instant. One of the two synchronous motors is connected to a standard source of frequency and the other to a source of frequency being studied. This can for example be a power system in which case the line drawn on the paper chart will be an accurate record of the integrated system frequency. A small section of such a chart is shown in figure 7, curve Q. This record was made on one of the big eastern power systems and shows on a very open scale the integrated speed fluctuations which are continually taking place. In this particular chart the fine graduations are one-fifth of a second or 12 cycles apart. Consequently, it is possible to read extremely small frequency errors with high precision, far exceeding any of the ordinary graphic frequency recorders.

The slope of the curve is a measure of the instantaneous frequency. The transverse lines in this particular record are one hour apart. Consequently, a frequency error of $^1/_{100}$ of a cycle corresponds with a time error of six-tenths of a second per hour or an angle of about 45 degrees. An error in frequency considerably less than $^1/_{1,000}$ of a cycle can easily be seen. The kind of speed regulation on a system whether by ordinary governors supplemented by manual adjustment or by some type of automatic frequency controller, will determine the form of curve Q so that considerable information may be obtained from this record.

Figure 7, curve S, which is made by comparing one of these new time standards running at fixed temperature with another operating at variable temperature, shows very clearly the high precision of the instruments. The temperature variations to which the second instrument was subjected are shown in curve T. It is interesting to compare curve Q with curve S and observe how far short of perfection system frequency is at the present time, although for most commercial purposes it is very satisfactory.

For certain requirements, precisely controlled frequency of this kind may be very important. For example, in driving large telescopes in astronomical observatories it is necessary that the image of a star

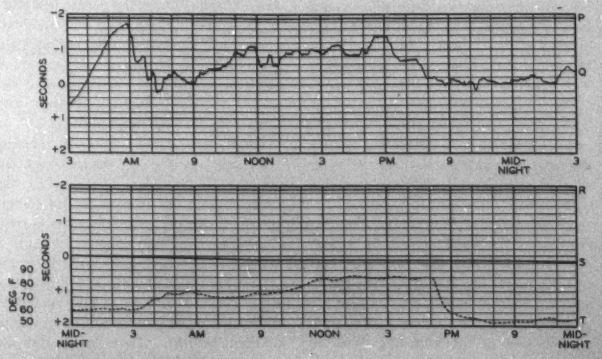


Figure 7

P and *R*—Reference lines drawn by stationary pen

Q—Integrated frequency of power system

S—Time rate with corresponding temperature variation *T* of vibrator unit

or other heavenly body should be held stationary in the field of the telescope for the purpose of making photographs which sometimes require hours of exposure. Since the telescope is swinging about an axis parallel to that of the earth one might suppose that the rate of angular motion should be exactly uniform to follow a star. Actually, it is necessary to vary this motion slightly because the refraction by the earth's atmosphere increases steadily from the zenith to the horizon.

Obviously, one of the best means of driving a telescope is a synchronous motor but if such a motor is supplied with alternating current of perfectly constant frequency some mechanical means is needed to adjust for the slight apparent error in stellar motion. The difference in motion of other heavenly bodies such as a planet or the moon would of course require a much greater adjustment of the rate.

From this explanation it will be appreciated that this new time standard contains within itself means for extremely precise and easily controlled rate adjustment and that it can supply alternating current to a synchronous motor driving a telescope so that the latter will accurately follow the motion of a heavenly body. The method of adjustment in the case of a star where the rate varies from the zenith to the horizon may become automatic through the use of suitable cams. Thus after the telescope has once been focused on a star the image will remain stationary in the telescopic field without any manipulation by the observer.

Utilization of this instrument for the purpose of driving telescopes is only one of a great many possible applications. To the scientist and engineer it may prove another useful implement in the endless campaign of progress.

Discussion

C. W. La Pierre (General Electric Company, Schenectady, N. Y.): The ordinary time standard, as we know it, is usually based upon either the gravitational constant or upon the physical constants of a particular material. The pendulum is an example of the first, and tuning forks and crystals are examples of the second. Mr. Warren has combined these two means of getting a time standard in such a way as to provide gravitational rate control such as is used by the pendulum with vibrational frequencies ordinarily associated with tuning forks. In this way, he has made provision for a very desirable feature, namely, ability to adjust the frequency of vibration over a fairly wide range. To those who have long desired an adjustable-frequency time standard, the new method opens many possibilities. Unfortunately, it also introduces into the time standard many of the difficulties of each of the previous basic methods.

As compared with the tuning fork, for instance, we find that the rate change for changes in amplitude is inherently somewhat worse than the corresponding change for a tuning fork. Mr. Warren has pointed out ingenious means for compensating for this amplitude effect.

With recent vacuum-tube circuits, the effect of amplitude change on frequency might be minimized by stabilizing the amplitude with the tube circuit. How this can be accomplished in tuning forks is described in Patent No. 2,147,492, M. S. Mead.

The ability of Mr. Warren's device to operate over a considerable frequency range by simple adjustment of current in a regulating coil is unique among standard-frequency sources. Unfortunately, we cannot regulate current to the same precision as we desire frequency. Otherwise, we could use current as the basic control for our frequency standard. In Mr. Warren's system, the error in current setting will result in a corrresponding error in only that part of the frequency which is dependent upon the flow of current. For instance, from Mr. Warren's figure 5, one-tenth ampere of current produces a change in frequency of approximately 2.3 cycles or a change in time of approximately 4,000 seconds per day. Therefore, if it is desired to operate 2.3 cycles from 50 cycles with a precision of one second per day, it would be necessary to maintain the current constant to one part in 4,000. This might involve some problems over a considerable period of time. On the other hand, such a departure from the normal frequency is not to be obtained by any of the more usual mechanical timing oscillators.

In addition to rate changes due to amplitude and possibility of frequency adjustment, Mr. Warren finds with his device, as well as with the other devices, that temperature compensation is extremely important. Quartz crystal oscillators having a temperature coefficient of one part per million per degree centigrade are common. However, the coefficient for quartz varies with ambient temperature, and it is difficult to secure this coefficient except over a limited range of, say, -30 to $+50$ degrees centigrade. Tuning forks can be readily made with coefficients less than ten parts per million per degree, and by special heat treatment this might be reduced to about two parts per million. Satisfactory temperature regulation on fork and crystal oscillators is relatively easy to secure, although there is always the possibility, if not probability, that the thermostatic regulator will fail and cause difficulty. Mr. Warren's figure of approximately two parts per ten million per degree centigrade indicates that he has achieved an excellent temperature compensation in this device as compared to what we ordinarily produce in crystal or tuning-fork oscillators.

Arnold White (nonmember; General Electric Company, West Lynn, Mass.): The author should be complimented for bringing this new instrument to the attention of the industry. A real need exists for a simple secondary standard of time, free from the objectionable characteristics (as noted by the author) of the standards now in use. Such a standard would enable the meter and instrument engineers to develop new test equipment which would expedite and simplify the calibration of watt-hour meters and frequency meters. For example, in the calibration of watt-hour meters, the number of revolutions of the meter disk must be counted and timed. This usually is accomplished by the test man holding a known load while visually counting and timing (by means of a stop watch or clock) the revolutions of the meter disk. This presents many chances for personal errors. Any methods frequently used to calibrate watt-hour meters, employing a light beam, photoelectric cell, and synchronous timer to count and time automatically the revolutions of the meter disk, offers a large saving in time and reduces the chances for personal errors to a minimum. The successful operation of this system depends on the availability of a source of constant frequency (such as is obtainable from a quartz oscillator or tuning fork) for operating the synchronous timer. However, due to the large investment in the source of constant frequency, this system, up to the present, has only been within the reach of the larger laboratories. It is hoped the new standard of time will bring this method of meter calibration within the reach of the smaller laboratories. The author does not show what effect, if any, local interfering vibration has upon the constancy of frequency. It is believed the same type of interference received through the base of a tuning fork and affecting its frequency may also affect the frequency of the vibrator unit thus necessitating the use of an interference absorbing mounting. The author suggests mounting the vibrator on a pier. We have had some experience with mounting a tuning fork on a pier. It was found that a pier did not materially reduce the interference from the earth tremors caused by trucks and other heavy machinery operating in the vicinity of our building. After trying several forms of Julius suspensions with little success, we found that a piece of slate (taken from an old switchboard) about two feet square and two inches thick mounted on four soft rubber balls about four inches in diameter (purchased at a local five-and-ten-cent store) relieved the situation entirely.

Henry E. Warren: Referring to C. W. La Pierre's comments, in addition to the very great reduction in rate change for changes in amplitude by the method suggested in the paper, the vacuum-tube circuit is so arranged as to hold the oscillating wire at almost constant amplitude so that time errors due to variations in voltage are very small indeed. The adjustment of rate by variations of the current in the regulating coil which adds to or subtracts from the gravity force would not ordinarily be used over a large range or for a long time. This feature is most important perhaps in regulating the angular motion of large telescopes where the rate variations due to changes in the atmospheric refraction between the zenith and the horizon and errors in the gear-tooth spacing, etc., are very small so that there should be no difficulty in holding the regulating current to the precision desired. If such a

Testing of Distribution Arresters

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MEMBER AIEE

THE testing of distribution lightning arresters, especially those removed from service, has increased sharply in recent years. Such testing by utilities is considered in this paper as distinct from design and routine tests made by the arrester manufacturers.

While check tests on new designs of line-type distribution arresters (rated at 15 kv and less) are sometimes made by utilities to insure that new arresters have the desired characteristics and meet specification requirements, yet few utilities make routine tests on new arresters. There seems to be little need for such routine tests in view of the good quality of present-day arrester design, manufacture, and factory tests.

Arresters in service, however, are mostly of types made about five years ago and earlier and in many cases are now known to have had originally or to have developed some deficiencies. Arrester failures or lack of adequate lightning protective characteristics have not usually been sufficient to warrant wholesale replacements or the trouble and expense of testing at the installations. In a very few cases operating experiences have justified complete replacement of some types of arresters manufactured 15 to 20 years ago.

Arresters removed from service incidental to other work, however, may or may not be in suitable condition for reinstallation. Routine inspection of such arresters, of course, serves only to eliminate those which are broken or damaged externally. In a few cases, operating experience has demonstrated that certain types should be junked upon removal.

For a large majority of arresters removed from service, information in this paper indicates that routine testing of the proper type makes available at relatively small expense arresters which are suitable for re-use. Blind junking of all distribution arresters removed from service, regardless of type, seems to be wasteful.

At the request of the AIEE lightning arrester subcommittee, the experiences of utilities with various test methods were obtained by the author for technical study.

Present Status of Arrester Testing

A questionnaire was sent in January 1939 to 55 operating companies. Replies were received from 52 companies.

Twenty-nine companies reported that tests of various types are an established procedure for distribution arresters, with only six of the companies testing new arresters. These companies included most of the largest utilities and a number of the smaller ones, all located east of the Rocky Mountains.

Table I shows a summary of test methods in use for new arresters and for arresters removed from service, as well as related cost data where furnished. Numbers were arbitrarily assigned to the 29 companies reporting tests. These utilities have been making tests on used arresters for periods ranging from 1 to 11 years, except that one company has been making 60-cycle withstand tests on removed arresters for 24 years. Six companies also test new arresters and one tests arresters at installed locations. Usually more than one type of test is applied by each utility.

Over 150,000 arresters removed from service due to causes other than trouble associated with the arresters themselves have been tested by the 29 companies. Probably over 40,000 arresters when new have been given routine tests, mainly by two utilities.

A detailed analysis of the data submitted in reply to the questionnaire is given in the following discussion, taking each type of test separately. As all of the 29 reporting companies made tests on removed arresters (see reference 1 for a description of some test methods) such tests will be discussed first.

Tests on Arresters Removed From Service

Impulse Tests

Routine impulse tests on removed arresters are made by three of the companies reporting. Company 7 makes impulse tests on 3-kv arresters in accordance with AIEE Standards No. 28 for lightning arresters, using a portion of a 650-kv surge generator with 2,300-volt power follow supply. Characteristics are observed on a cathode-ray oscilloscope. Company 8 follows AIEE Standards No. 28, except that it uses surge currents of about 3,000 amperes with a 0.5x150-microsecond wave. This company uses a 100-kv surge generator with power follow supply at 2.8 and 5.6 kv for 3- and 6-kv arresters, respectively. Surge voltage is measured by sphere gap. Company 20 uses a 100-kv surge generator with a 1.5 x 40-microsecond wave and 1,200-ampere surge current. A 60-cycle voltage of 4 kv is applied to 3-kv arresters during impulse tests. This is quite severe.

Arresters rated at 3 kv are rejected by company 7 if their spark-over voltages are outside the range 8 to 14 kv or 14 to 20 kv, depending upon arrester manufacture. These limits, which agree reasonably well with the published range[2] of 12 to 22 kv for new arresters, were established by values found for new arresters.

Company 8 rejects arresters which have discharge voltage (*IR* drop) at 3,000 amperes exceeding 30 to 37.5 kv for 3-kv arresters and 35 to 47 kv for 6-kv arresters, the values used depending upon manufacture. These limits, which exceed the published maxima[2] of 15.5 and 30 kv by large margins, were selected to eliminate arresters having characteristics too far above the average for new arresters, and may be too liberal.

Company 20 has no limits other than failure to interrupt power follow current on surge test.

No information on rejections was given by company 7. For company 8, 4,167

Paper 39-129, recommended by the AIEE committee on protective devices, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26-30, 1939. Manuscript submitted April 14, 1939; made available for preprinting May 24, 1939; released for final publication September 1, 1939.

Herman Halperin is assistant equipment and research engineer, Commonwealth Edison Company, Chicago, Ill., and sponsor of testing of distribution arresters, AIEE lightning arrester subcommittee.

The author acknowledges the co-operation of 29 utilities in furnishing extensive data and the valuable assistance of E. H. Grosser in preparing the paper.

gross shift in frequency as two cycles were to be held over a period of a day a major correction could be readily made by adding or subtracting suitable weights.

External vibration if transmitted to the oscillating wire of this time standard may have a detrimental effect but this effect is greatly reduced in the instrument itself by the use of soft springs which support the heavy mass to which the upper end of the wire is fastened. Further absorption of external vibration by simple means like that suggested by Arnold White seems desirable for locations where vibration is considerable.

arresters, or about five per cent of all arresters returned from service, have been rejected for failure to meet impulse and 60-cycle withstand tests. Their records do not differentiate between the two causes of rejection. Only about one per cent of the used arresters tested by company 20 have been rejected on impulse tests.

The impulse test is the only test which serves to indicate the ability of the arrester to protect equipment and to interrupt power follow current. A relatively simple test method appears to be that of company 20, if follow current at a suitable voltage is supplied by a transformer having bushings gapped to an impulse flashover voltage slightly higher

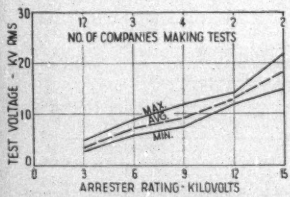

Figure 1. Sixty-cycle withstand test voltages in use for distribution arresters removed from service

than the normal characteristic of a satisfactory arrester. Inadequacy of the arrester is indicated either by bushing-gap flashover or by automatic opening of the supply to the transformer.

Thorough testing for impulse characteristics should follow AIEE Standards No. 28.

The experience of companies 8 and 20 indicates that changes in the impulse characteristics of arresters occur in service in relatively few cases, and that impulse tests are not needed ordinarily. Company 17 also found this indication based on impulse tests on a few moderately corroded arresters of one type.

Sixty-Cycle Withstand Test

As the name implies, this test consists in applying a predetermined value of low-frequency voltage across the arrester terminals for a definite time, usually one minute. Spark-over of the arrester gap, evidenced by appreciable current flow in the circuit, and opening of the power supply by overload relay, is taken as cause for rejection.

Test voltages in use by 13 companies are summarized in figure 1. Tests are made at voltages ranging from 83 per cent to 167 per cent of arrester-voltage ratings, the average being 113 per cent. Five companies test at rated voltage.

Five companies reported data on rejections based on the 60-cycle withstand test. For tests at average voltages of 1.0, 1.1, 1.3, 1.3, and 1.5 times rated arrester voltages, the rejections in this test were roughly 0, 5, 0.1, 15, and 1.5 per cent, respectively. These results, which are probably obscured by other factors, give no indication that the higher test voltages result in a larger number of rejections.

Seven of the companies have dissected arresters rejected in the 60-cycle withstand test. The most common findings were as follows: corroded gap assemblies (seven companies); moisture in gap assemblies, gap welded, foreign particles from the valve element in gap assemblies, porcelain gap spacers cracked, and valve element punctured or damaged (each reported by one company). One utility which found corrosion in many cases reported that no trouble was apparent in some dissections of rejected arresters.

It is probable that test voltages equal to, or little more than, the rated arrester voltage could be depended upon to reject only those arresters having serious internal defects. The test, in general, is apparently not severe, since much higher percentages were rejected in other tests by other companies. Arresters rejected in this test have generally, but not always, revealed internal defects when dissected. Nine of the 13 companies making 60-cycle withstand tests, however, state that the test is satisfactory; no statement was received from four companies.

This test, even when used at slightly above rated voltage, is to be recommended only because of its simplicity. It should not be considered an infallible test for defects, but should be used in conjunction with other tests.

Sixty-Cycle Breakdown Voltage Test

This test has been used by 15 utilities, for periods ranging from 1 to 11 years, to check arresters returned from service. As shown in table I, 9 of the 15 companies also make 60-cycle leakage-current tests, using the same circuit as for the breakdown test, and three companies make breakdown tests and Megger or resistance measurements.

The circuits used for making 60-cycle breakdown tests consist of a variable-voltage testing transformer or a transformer with induction regulator or tapped autotransformer in the low-voltage circuit, a voltmeter connected to the transformer voltmeter coil or to a separate potential transformer, or (company 22) an electrostatic voltmeter, and a series resistor for limiting the current in the circuit at arrester breakdown. This resistor may be located in either the low-voltage or high-voltage circuit, as has been illustrated.[1]

Eleven of the companies employ resistors in the high-voltage circuit, two (one of which, having two test circuits, is also included in the preceding group) use resistors in the low-voltage circuit, two use no resistors but depend on the impedance of the testing transformer, and one gives no information. The ohmic values of series resistors used range from a fraction of a megohm to 100 megohms. These resistances were selected to limit the current through the arrester during breakdown to values, calculated from data submitted to the author, ranging from less than 1 milliampere to 25 milliamperes. The average of maximum permissible currents in tests by

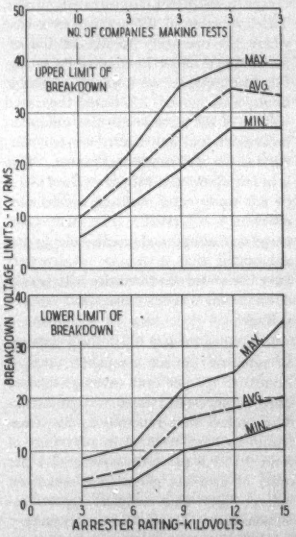

Figure 2. Acceptable limits of 60-cycle breakdown voltages in use for arresters removed from service

nine companies was approximately 14 milliamperes. One of these companies used two values of limiting current, 10 and 20 milliamperes, for different makes of arresters. Another company, not included in this average, used an overcurrent relay to trip the low-side breaker in about 15 cycles for currents of 15 to 35

milliamperes, but used no series resistor.

Only two companies regularly make correction for the voltage drop in the high-side series resistor, in determining the arrester breakdown voltage. A third company makes this correction only for arresters having resistance shunted gaps, where the leakage current prior to breakdown is appreciable. For arresters with ordinary gaps and such that they would not be rejected in the leakage-current test, the drop through the current-limiting resistor would probably be negligible. Where the current-limiting resistor is placed in the low-voltage circuit, no correction, of course, applies, since voltage measurement is always made with respect to the high-voltage circuit.

Limits of acceptable 60-cycle breakdown voltage are shown in figure 2. Minimum acceptable breakdown voltages for arresters returned from service range from 0.7 to 2.8 times arrester rated voltage, and maximum acceptable breakdown ranges from 1.8 to 4.0 times rated voltage. The low value of 0.7 applied to a case where the operating voltage of the arrester was a minor fraction of its rating. For 14 companies the average acceptable limits were about 1.3 times the rated voltage of the arrester for the minimum breakdown and 3.0 times the rated voltage for the maximum breakdown. This is in fair agreement with the values of 1.5 to 3.0 times rated voltage which were previously suggested.[1] The 15th company has established no specific limits, but stated that a number of arresters have been returned to service with breakdowns as high as 3.4 times rated arrester voltage.

Rejections for low breakdown voltage, as reported by six companies, ranged from 0 to 6.7 per cent (average 2.0 per cent) of arresters tested. High breakdown values were reported by five companies to have resulted in rejections of from 0 to 2.8 per cent (average 1.4 per cent) of arresters given the breakdown voltage test. One company reports rejections of one per cent for unsatisfactory breakdown action, that is, gradual breakdown, or high resistance after breakdown. Total rejections by seven companies in the 60-cycle breakdown voltage test averaged 4.1 per cent, and ranged from 0 to 8.8 per cent.

An attempt was made to determine whether the rejections in this test were related to the rejection limits used. No correlation could be found, either for lower or for upper limits.

Arresters rejected in this test have been dissected by nine companies, to determine the causes for unsuitable breakdown values. Usual findings were: gap electrodes pitted, burned, or springs broken (six companies); gap assembly corroded or contained moisture (five companies); foreign particles in gap assembly (one company); valve element damaged or wet (two companies). The most usual causes for low breakdown were gaps pitted and gaps shorted by corrosion or burning; for high breakdown, damaged gaps or deteriorated springs, resulting in increased gap separation. The one company (number 17) giving unsatisfactory breakdown action as cause for rejection finds each of the above causes to be responsible in varying degree. One company (number 14) included above, however, stated that no correlation was found for high breakdown voltage, and another (number 15) that, in general, no correlation seemed to exist between test results and arrester condition.

Two utilities sent in the results of dissections in some detail. One (number 12) found low breakdown voltage to be associated with pitting or corrosion of gap assemblies in each of 11 arresters dissected, but dissections of 14 arresters having breakdowns of from 4.1 to 5.6 times rated voltage failed to reveal any defects in nine cases. The other (number 25) found deteriorated metal parts in several arresters rejected for low breakdown.

A review of this test method, which is extensively used, indicates that it is mainly useful as a means of detecting internal defects, particularly in metal parts, when applied in conjunction with leakage-current measurements or megger testing. While low breakdown voltage is generally associated with defective conditions, this has not always been found for high breakdown voltages. It seems undesirable to employ the same upper breakdown limits for all makes and types of arresters used on a system, but such limits should be determined for each type by tests on good arresters. The test is more informative than the 60-cycle withstand voltage test.

Table I. Tests Made on Distribution Arresters by Utilities

Company Number	Test Method: Impulse Voltage	60-Cycle Tests: Withstand Voltage	60-Cycle Tests: Breakdown Voltage	60-Cycle Tests: Leakage Current: Microammeter	60-Cycle Tests: Leakage Current: Milliammeter	60-Cycle Tests: Leakage Current: Neon Tube	Megger or Resistance Bridge	Radio Interference or Ionization
Number of years test has been in use on arresters removed from service:								
1								1
2		24						
3		0					4	
4		7						
5		0	Several					Several
6		9						9
7		7	3				3	
8		5*	9*					3*
9			1	1			1	1
10						10**		
11			1	1				
12			4					
13			10		3			3
14			1½					
15			1½				1½	
16			2*	2*				2*
17			6	6				
18			10*					10
19		5						
20		2	2	2			2	2
21		9*	7*		9*			
22			11		11	11		
23			2	2				
24		6						6
25			2*			2*		
26		9*						9
27		1						
28		6						6
29							5	
Average years in use		4.7	7.0	4.4	2.4	8.3	6.5	2.8	4.7
Number of companies using test for:								
New arresters	1	3	4	1	1	1	0	2
Used arresters	3	13	15	5	4	2	6	12

* These tests are also made on new arresters.
** Approximate or estimated.

Sixty-Cycle Leakage-Current Measurements

Such measurements have been used for periods ranging from 1 to 11 years by ten companies. Only one utility (number

Table I (Continued). Tests Made on Distribution Arresters by Utilities

Company Number	Number of Arresters Tested: Arresters Removed From Service	Number of Arresters Tested: Part or All of New Arresters	Per Cent of Arresters Rejected by Test: Arresters Removed From Service	Per Cent of Arresters Rejected by Test: New Arresters	Testing Cost per Arrester Tested	Testing and Rehabilitating Cost per Arrester Returned to Stock
1	500	0	5.0		—	$0.50 to 0.75
2	8,500	0	1 to 2		—	0.84
3	1,200	0	58			
4	?	0	?			
5	500/yr.	0	?		—	0.50 to 1.00
6	?	0	6 to 10		$0.10	1.10**
7	350	0	?		0.50 to 0.75	—
8	85,000	10,050	5.6	0	0.04	0.30
9	717	0	17		—	0.60**
10	16,000 (in 4 yrs.)	0	16			
11	500	0	24		—	0.15 to 0.25
12	2,375	0	2.9		0.15 to 0.25	1.30 to 1.40
13	2864	0	20		0.25	2.00**
14	200	0	40†			
15	1,485	0	9.8		—	0.28**
16	1,477	195	23	16	0.50	0.94
17	6,600	2,200‡	8.3	Few	0.35	1.12
18	?	?	Few	Few		
19	393	0	15		0.20**	—
20	1,919	0	3.0		0.35	—
21	6,882	25,508	7.2 (incl. new arr.)		—	0.75 to 1.00
22	4,571	0	20†		—	0.60
23	4,100	0	10			
24	?	0	?		0.10**	
25	?	?	?	?		
26	?	?	30**	0		
27	20	0	0			
28	192 (1938)	0	22			
29	?	0	<5			
Total or average	143,267+	37,953.+	9.4** (weighted average)		$0.27 (average)	$0.83 (average)

† Includes rejections due to mechanical defects.
? Means no data submitted, or utilities had no records readily available.
‡ Since 1936.
‡ Routine test on new arresters has been discontinued by this company.

10) tests for leakage current with no corresponding breakdown voltage test.

In general, the same test circuit is used for leakage and breakdown measurements, and consists of a variable high-voltage supply to the arrester, and series meter for measuring the leakage current (and small charging current) of the arrester under test. No attempt is made in most cases to shield the meters from stray fields as this is done by only two companies reporting. One company (number 10) wets down arresters before testing.

Current through the arrester at rated voltage is measured by five companies by means of microammeters, capable of indicating minimum values ranging from 4 to 50 microamperes. Three companies (numbers 10, 21, and 22) use milliammeters with minimum readable currents from 100 to a few hundred microamperes. Company 22 uses the milliammeter partly for routine tests and partly as a reference instrument; routine checks are also made by connecting an ordinary three-watt 110-volt neon lamp, with resistor in base removed, between arrester ground lead and ground. The tube glows brightly for currents greater than about 250 microamperes. Company 25 employs a neon tube in a somewhat different manner; it is connected across an 0.45-megohm resistor inserted in the arrester test circuit and glows at a critical voltage of 90 volts, corresponding to a leakage current of 200 microamperes. Company 13 uses a cathode-ray oscilloscope coupled to the circuit as a milliammeter, with minimum indication at about one milliampere.

For the five companies using microammeters, four reject used arresters if leakage current at rated arrester voltage exceeds 150 microamperes—one of these (number 9) is considering a lower value for future use; the fifth company (number 16) has an upper limit of 50 microamperes for arresters. One of the four companies using 150 microamperes as a general limit (number 17) accepts one type of arrester conditionally if leakage current is between 150 and 500 microamperes, and is tagging such arresters for future identification. Company 11 has found that serious corrosion exists in this same type of arrester only where leakage currents exceeded 300 microamperes, and is conducting more inspections to establish a separate limit for this type, to supplement the 150-microampere limit for some other arresters.

Limits set by companies using milliammeters are usually minimum readable current values, which correspond to several hundred microamperes for company 10, about 250 microamperes for company 21, and about one milliampere for company 22. Companies 13 and 25, using special methods as mentioned above, have limits of about one milliampere and 200 microamperes, respectively. All limits refer to tests at rated arrester voltage, except those for company 22, which tests 9- and 15-kv arresters at rated voltage, 3-kv arresters at 4 kv, and 6-kv arresters at 5 kv, and for company 25, which tests 3-kv arresters at 2.4 kv and 12-kv arresters at 8 kv.

Six companies, three using the 150-microampere limit, gave data on rejections in this test. The rejections ranged from 5.3 to 16 per cent. The average rejections for limiting leakage currents of 50, 150, several hundred, and 1,000 microamperes were 14, 9.6, 16, and 5.3 per cent, respectively.

Dissections of arresters rejected in this test by eight companies showed corrosion of gap assemblies in most cases. Damaged gap assemblies were reported in some cases by two of these companies, and one company occasionally finds foreign particles in the gap assembly.

Test limits were set up by these eight companies on the basis of conditions found in dissecting arresters after test. Company 16 found that with leakage currents just above 50 microamperes many arresters showed corrosion, and practically all were corroded which had more than 100 microamperes leakage. Company 17 found that the limit of 150 microamperes at three-fourths of rated voltage (this limit now applying to tests at rated voltage) resulted in rejections of no arresters in good condition, about two-thirds of those with slight corrosion, and all badly corroded arresters. This is shown in figure 1 of reference 1. Company 23 supplied data for eight dissected arresters having leakage currents ranging from 155 to 400 microamperes which showed corrosion in each case. Arresters dissected by company 10 for a readable milliammeter value (several hundred microamperes) showed some defects in all cases.

Since these tests, with the two exceptions noted, are made at the rated voltage of the arrester, limiting leakage-current values appear to be about the same for different voltage ratings.

Tests on one type of arrester by com-

pany 17 have shown that 60-cycle breakdown and leakage-current measurements are practically independent of ordinary variations in ambient temperature, and that test results are reasonably reproducible over a period of several months after removing the arrester from the system.

In summary, the leakage-current test, used in conjunction with the 60-cycle breakdown test, has been used successfully by a number of utilities as a means of weeding out arresters unfit for further service.

Megger Test

Megger tests or other resistance measurements have been used by six utilities for one to five years. A 500-volt Megger is used by company 29, 1,000-volt Meggers by companies 3 and 9, and company 15 uses a 2,500-volt Megger; the Megger voltage is not stated by company 7. Company 20 uses a 12,000-megohm bridge. Limits are set at the following minimum values: company 15, 25 megohms; company 29, 100 megohms; company 20, 1,000 megohms; company 3, infinity. This is the only test used by companies 3 and 29. Companies 7 and 9 give no limits. One other company (number 13), which makes no routine Megger tests, considers this test helpful as an auxiliary check, if low enough limits are used.

The four companies having limits of 25, 100, 1,000, and infinity megohms report rejections in this test as 9.8, less than 5, 1.5, and 58 per cent, respectively. The use of the infinity limit by the latter company appears to be the cause of the unusually and, perhaps, unnecessarily high rejection rate. The 1,000-megohm limit is used by company 20 merely for rapid selection of defective units, before subjecting them to other tests.

Because of the simplicity of Megger testing, it is of interest to consider how this test compares in results with measurement of 60-cycle leakage current. Company 13 considers resistances of one megohm or less a definite indication of corrosion, but states that even with values above 20 megohms corrosion may be present. It is to be noted that the limits in use are all above 20 megohms. Data presented by company 15, covering dissections of 92 arresters, showed that the 25-megohm limit resulted in the rejection of all badly corroded and most of the moderately corroded units. Only 15 per cent of the arresters with slight corrosion and 7 per cent of those in good condition had Megger readings which would have resulted in their rejection. Company 29 found either corrosion or dust from the valve material in the gap assemblies of practically all arresters rejected in this test. Company 7 found no corrosion in arresters having Megger readings of 2,000 megohms or more, but reported one arrester with zero Megger reading which was badly corroded, and one reading 200 megohms where the gap chamber contained a web-like fungus growth.

Another company, number 9, gave corresponding 60-cycle leakage current and Megger data on over 400 arresters. A fair relationship is shown by these data, which on analysis indicate that corrosion conditions could be detected about equally well either by the 150-microampere maximum in the 60-cycle leakage current test or by a minimum of about 25 megohms in the Megger test. This company stated, however, that it is still unable to set up definite limits within which Megger readings should fall to give an accurate indication of the internal condition of the arrester, but that in the absence of other test facilities in the field the Megger is of some value in detecting moisture. They are considering a survey by Megger test of all arresters at 13.2-kv substations.

An arrester manufacturer who has conducted numerous tests on used arresters returned to the factory reports that no correlation has been found between Megger readings and arrester condition or ability to perform properly. This manufacturer prefers the 60-cycle leakage-current test, which, however, it does not consider infallible.

Considering each test by itself, then the Megger test is the simpler of the two methods. Where 60-cycle breakdown tests, however, are made, the leakage-current measurement, which appears to be the more positive test, is to be preferred, since little additional testing equipment is required. When, as, and if tests on installed arresters become advisable, the use of only the simple Megger test may be attractive.

Radio-Interference and Ionization Tests

Such tests are made by 12 companies, including two companies (numbers 13 and 16) who make ionization tests. The functions of the two tests are essentially the same, that is, to detect high-frequency oscillations set up by corona discharge within the arrester.

Radio-interference tests are made by the five utilities who described their test method by merely operating a sensitive radio set near the energized arresters. One company (number 1) mentions a separation of eight feet between the arrester and radio set antenna. Perhaps the test conditions are unnecessarily severe since arresters in service are usually relatively far from customers' equipment.

Company 8 uses a portable battery-fed receiver with a milliampere meter added to the output circuit, but ordinarily, as with the other four companies, depends on the noise from the loud-speaker. A sixth company (number 20) also uses a conventional broadcast receiver, but coupled to the primary lead of the arrester test circuit through a tuned coil and shielded lead.

Ionization tests, as used by companies 13 and 16, employ a cathode-ray oscilloscope either coupled to the arrester circuit through an air-core transformer or connected across a series inductance inserted directly in the circuit. Arresters are rejected in this test if high-frequency oscillations appear on the oscilloscope screen when the arrester is energized at the rated 60-cycle voltage of the arrester (company 13) or 1.33 times the arrester rating (company 16).

In order to pass the radio interference test, no radio noise must be noted when the arrester is energized at operating voltage (company 8), operating voltage plus one kilovolt (company 6), rated arrester voltage (companies 5, 24, and 26), or 0.83 to one times rated voltage (company 9). Company 20 tests at rated arrester voltage for arresters having Megger readings more than 1,000 megohms and at 1.33 times rated voltage for those showing less than 1,000 megohms. Company 1 applies eight kilovolts between arrester and mounting bracket in this test for both three- and nine-kilovolt arresters. The test voltage was not stated by two companies.

Arresters which fail to pass the radio-interference test of company 6, but which appear otherwise satisfactory, are dried out in an oven at about 70 degrees centigrade for 36 hours and then retested. About half of these arresters are reclaimed by this procedure. Company 17 made a trial of a similar procedure and found considerable reduction in 60-cycle leakage current for only those arresters which had visible cracks in the sealing compound; hence, it was concluded that this improvement was not likely to be permanent.

Rejections in this test, for six of the companies, ranged from 0.5 to about 11 per cent, with an average of about 3.8 per cent of arresters tested. Four companies report that arresters thus rejected show, on dissection, corroded or damp

gap assemblies or loose gap structures.

Some data are given for one of the largest urban systems, which indicate that radio-interference troubles due to faulty arresters may be too few to warrant this type of test. Field investigation of 543 complaints of radio interference during the past six years showed that the utility's equipment was responsible in only 12½ per cent of the cases, and that only ten or 1.8 per cent of all complaints could be traced to faulty arresters. This particular company does not test arresters for radio interference.

Radio-interference or ionization tests appear desirable as a means of reducing radio interference caused by arresters on distribution systems only where this trouble exists to a serious extent. Where such tests are made to determine radio-interference levels likely to cause complaints in service, the method described in EEI Publication No. C-9, "Methods of Measuring Radio Noise," is recommended.

Leakage Over Porcelain

Company 21 includes in its routine tests on new and used arresters a test for "leakage over porcelain." Twice rated 60-cycle arrester voltage plus 1,000 volts (except three-kilovolt arresters, which are tested at 10 kilovolts) is applied between the line lead and hanger bracket, and leakage current over the arrester body measured with a milliammeter. The maximum permissible leakage current is five milliamperes. No data were given to correlate test results with arrester conditions.

Tests on New Arresters

As shown in table I, routine tests on new arresters are made by six companies: three (numbers 21, 25, and 26) testing all new arresters, two (numbers 8 and 16) ten per cent of arresters purchased, and one (number 18) three arresters of each rating from every shipment received. Tests are made in the same manner as the tests previously described for arresters removed from service. The test limits are the same as for used arresters for these companies, except that company 16 has a 30-microampere limit in the 60-cycle leakage test.

Data regarding rejections of new arresters on routine tests were supplied by companies 8 and 26, reporting no rejections in more than 10,000 tests, and by company 16, which rejected two arresters out of 195 (representing 1,950 arresters purchased). Company 17, which no longer tests new arresters except for new designs, in earlier tests on 2,200 new arresters rejected very few by test.

These practices and results indicate that routine testing of new arresters by the purchaser may be difficult to justify. Tests on new designs and occasional check tests on representative arresters purchased, however, may be of value.

Tests on Arresters in Service

Radio interference tests are made in the field by company 7 on installed three-kilovolt arresters, incidental to this company's general investigations of radio interference complaints. Measurements are made with a portable radio set, the output of which is determined using an attenuation box. The detection of defective arresters is often aided by jarring the pole with a sledge hammer, but positive localization requires disconnecting the arrester from the line during noise level measurements.

Interference from arresters was reported to be caused most often by moisture and corrosion in the gap chamber. Of approximately 1,000 arresters checked in the field each year for radio interference since 1924, about 100 arresters have been removed annually and scrapped.

Test Combinations in Use

As shown in table I, testing procedures in use generally include more than one type of test, each test as a rule serving to detect specific types of defects. The most usual combinations, where all types of tests are considered, include: 60-cycle breakdown and leakage current (five companies); 60-cycle withstand and radio interference (five companies); and 60-cycle withstand alone (four companies). Excluding impulse, radio interference, and ionization tests, the most common combinations are: 60-cycle withstand alone (ten companies); 60-cycle breakdown and leakage current (seven companies); and 60-cycle breakdown alone (four companies).

Economics of Arrester Testing

Data on the costs of testing and rehabilitating arresters removed from service, as given by 14 companies, are included in table I. Two cost figures are shown: the testing cost per arrester exclusive of fixed and maintenance charges of the testing equipment, and the cost of tests and repairs per arrester returned to stock. The latter figure includes the cost of work on arresters which were found unsuitable for re-use, prorated as to each arrester accepted.

Testing costs range from 4 to nearly 75 cents, averaging about 29 cents per arrester tested. These costs apparently vary widely with local conditions, since they bear no relation to the number or types of tests made.

Total costs per arrester found to be in condition suitable for re-use range from about 20 cents to $2.00, and average about 83 cents. These costs vary widely due to local conditions as well as to the amount of repair work done. Company 6, reporting a total cost of $1.10 per arrester, replaces broken leads and caps and bakes out those arresters which initially fail to pass the radio-interference test. The total cost of $1.30 to $1.40 per arrester given by company 12 includes increasing the length of the line lead in all cases. Costs for neutral gaps are given as 69 cents by company 17, as compared with $1.12 for three-kilovolt phase arresters, the difference resulting from less repair work required.

Costs for testing and rehabilitating arresters of different voltage ratings are reported to be essentially independent of rating by companies 1, 5, 12, and 15.

The average cost of testing and rehabilitating arresters for re-use amounts to between 5 and 15 per cent of the new arrester cost, for ratings of 3 to 15 kv. Assuming that the useful life of the rehabilitated arrester is equal to one-half of the life of arresters now made, then, for example, there appears to be a saving of the order of 65 per cent in re-using 3-kv arresters after thorough test, over the cost of replacement with new arresters. For higher voltage ratings the economic advantage of testing arresters is more pronounced.

General Summary for Used Arresters

A summary of the test methods in use, together with conditions and defects indicated by each test, is given below for purposes of comparison:

(*a*). *Impulse Tests.* Impulse characteristics; ability to interrupt follow current.

(*b*). *Sixty-Cycle Withstand.* Following to a serious extent: corrosion; damaged gaps or valve elements; foreign particles in gap.

(*c*). *Sixty-Cycle Breakdown.* Pitted, burned, or corroded gaps; broken springs; foreign particles in gap; damaged or wet valve element.

(*d*). *Sixty-Cycle Leakage.* Corrosion; other conditions to a limited degree.

(*e*). *Megger.* Corrosion; other conditions to a limited degree.

(*f*). *Radio Interference or Ionization.* Conditions, such as corrosion or loose contacts, causing radio interference.

Test method (*a*) serves the purpose of checking the protective characteristics of the arrester, while the other methods are used to determine the physical conditions of the arrester as affecting the expected electrical characteristics in future service. Test methods (*b*) and (*c*) serve somewhat the same purpose, although method (*b*), the simpler test, is less effective than method (*c*). Likewise, methods (*d*) and (*e*) are similar in objectives; test (*e*) is relatively simple and inexpensive, but not proved as reliable; method (*d*), however, may be readily combined with test method (*c*), where used, and may be more successful under usual conditions.

In general, testing costs represent a small proportion of the costs of restocking good used arresters, and so differences between costs of tests may be unimportant. This is, of course, only true where sufficient arresters are to be tested to justify initial costs of testing equipment.

Suggestions for Testing Used Arresters

For routine tests on arresters removed from service, suggested combinations of tests which have been found to be simple and effective, and which require little complicated or expensive apparatus are as follows:

1. Sixty-cycle breakdown and leakage current measurements.
2. Sixty-cycle breakdown and Megger tests.
3. Sixty-cycle withstand and leakage current (or Megger) tests.

In conjunction with any of these test combinations, radio interference or ionization tests may be used, where such testing is warranted by local radio-interference conditions. Also, occasional or routine impulse tests may be made on used arresters where suitable equipment is available.

Based on present practice and results of tests in use, test limits suggested for trial use by utilities starting routine testing of arresters returned from service are given below:

Impulse Test. Use reference 2 as a general guide for voltage limits, but modify them in accordance with testing experience with used arresters.

Sixty-Cycle Withstand. Test at 1.0 or $1^1/_4$ times rated arrester voltage.

Sixty-Cycle Breakdown. Acceptable voltage range: $1^1/_2$ to 3 or 4 times rated arrester voltage.

Sixty-Cycle Leakage Current. Maximum at rated arrester voltage; 150 microamperes or lowest reading on milliammeter scale.

Megger. Minimum: 25 megohms. Preferable to use 1,000- or 2,500-volt Megger.

Radio Interference. Test at rated arrester voltage.

These values should be considered as tentative and should be modified as found necessary to meet individual conditions after the testing program has been started and a number of arresters, which on test show values both above and below the trial limits, have been dissected.

References

1. Testing and Application of Lightning Arresters, AIEE Lightning Arrester Subcommittee Report. AIEE Transactions, 1939, page 68 (February section).

2. Distribution Lightning Arrester Performance Data, AIEE Lightning Arrester Subcommittee Report. Electrical Engineering (AIEE Transactions), volume 56, 1937, page 576.

Discussion

E. J. Allen (General Electric Company, Pittsfield, Mass.): The replies from 29 companies now engaged in the testing of distribution lightning arresters have been well analyzed and presented. In view of the diversity of methods employed by the different companies making the six classifications of tests shown on table I, it would be of interest to determine what reasons govern the particular choice of some of the tests and what they were intended to demonstrate. In the best interests of uniform interpretation of data obtained from testing of distribution arresters, it is obvious that uniformity in test methods need be followed.

Our experience as a manufacturer with new and used arresters has demonstrated that the already prescribed test which most nearly approaches actual service conditions is the "operating duty test" set forth in AIEE Standards No. 28, issue of March 1936. As the three companies making impulse tests on arresters apparently do so with combined power voltage, the term "impulse test" applying to these companies and used by the author would preferably be extended to the term "operating duty test" as designated in the Standards. This distinction is made, since without the combined power voltage there is no indication of the arrester's ability to interrupt follow current.

Contrary to the practice described by one company, the AIEE Standards do not specify that the power voltage applied to the arrester during the operating duty test shall be in excess of maximum arrester rating, as this is not a condition for which the arrester was designed. The operating duty test on three-kilovolt arresters with four-kilovolt power voltage applied, may result in unnecessary damage to the arresters and hence should be discontinued.

Notwithstanding the fact that the AIEE Standards "operating duty test" describe a single test that will probably tell the most about the operating condition of a lightning arrester, simpler tests have been sought for use either in the laboratory or field, that would be equally indicative. The 60-cycle spark potential, 60-cycle withstand voltage, leakage current, Megger, or resistance bridge tests are examples which are described in the paper and which are used the most in the order just stated. Since these tests are only partially indicative of the operating condition of the arrester, they are subject to the following limitations:

Sixty-Cycle Spark Potential Test

(*a*). The most that this test might be expected to show is either a short-circuited arrester or an open-circuited arrester.

(*b*). This test will not necessarily show a damaged valve element, presence of moisture, or otherwise disclose the valve or resealing characteristics of the arrester. It is not an indication of the impulse protective characteristics of the arrester or suitability of the arrester for further service.

(*c*). Unless extreme precautions are observed, either or both of the gap and valve elements in good arresters may be damaged and unless the results are intelligently analyzed, good arresters may be unnecessarily rejected. Since this test subjects the valve element to 60-cycle voltage in excess of its rating, tests should be limited to not more than three applications and spark-potential reading.

Sixty-Cycle Withstand Test

(*a*). This test will indicate only a short-circuited arrester. As the author points out, it should not be considered an infallible test for defects and should be used in conjunction with other tests.

(*b*). The power voltage applied should preferably not be in excess of the maximum arrester rating. If the applied voltage is 1.25 times maximum arrester rating, as suggested in the paper, care should be taken to avoid sparking over the arrester gap by switching surges incidental to the test, as such spark-over of the gap could destroy the arrester by application of power voltage above the arrester's maximum valve or resealing rating.

Leakage Current, Resistance Bridge, or Megger Test

(*a*). The most that this test might be expected to indicate is the possible presence of moisture or corrosion in the arrester elements that may or may not be injurious to the service operation of the arrester.

(*b*). This test will not necessarily differentiate between leakage current caused by external moisture, humidity or surface deposits, as against leakage currents caused by moisture or corrosion of internal elements. This test will not show an open-circuited arrester, damaged valve elements, or the protective characteristics of the arrester.

(*c*). While the leakage current measured at no greater applied voltage than maximum arrester rating would not be likely to damage it in any way, precautions are necessary to assure that the applied power voltage never exceeds the maximum rating.

(*d*). As the author mentions, the 60-cycle leakage-current test at maximum arrester voltage rating is to be preferred as compared with the resistance bridge or Megger

Hence, the simpler tests which show the operating condition of a lightning arrester only to a partial extent should not be taken in themselves as definite cause for arrester rejection. Such arresters might give many years of continued reliable protection.

The author's statement that there seems to be little need for tests on new arresters by the operating company is borne out in table I of the paper in which virtually no new arresters are rejected by any of the testing methods described in the paper.

Cost data has been included covering testing and repairing by the companies reporting. The average testing and rehabilitating cost per arrester returned to stock of $0.83 apparently covers only minor re-

The Direct-Acting Generator Voltage Regulator

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Synopsis: The principal factors involved in the design and application of direct-acting voltage regulators and their relations to each other are discussed in this paper. The mathematical method used for deriving these relations is outlined. Definite conclusions are drawn concerning proper operation and design of this type of regulator.

IN recent years increasingly wide use has been made of direct-acting voltage regulators. During this time, improvements in design and a better understanding of their characteristics have developed. This paper describes some of the improvements and presents a mathematical analysis of a regulating system including a generator and exciter with a voltage regulator. It will be seen that many of the improvements in design follow directly and logically from the results of the mathematical analysis.

Improvements in Design and Operation

The first requirement of a regulating device is that it hold the regulated voltage very closely to the desired value without hunting or instability. Its ability to do this is influenced by all the elements of the system, including the generator and its load, the exciter, and the voltage regulator. Therefore, in order to understand the factors involved it is necessary to study the system as well as the regulator itself. It has been found that essentially perfect regulation can be maintained by the modern regulator over a wide range of operating conditions with stability. This performance is achieved by utilizing an inherent nonlinear property of the resistance elements, by careful balancing of the electrical and spring torques at every point in the range, and by use of a stabilizing transformer.

The second important requirement of a regulator is that it make the necessary changes to return the voltage to normal as quickly as possible after any sudden change in the operating condition. The time for voltage recovery is also affected by the other parts of the system. All that the regulator can do is to go immediately to its extreme position for raising or lowering the voltage, and then as the voltage approaches normal, fall back in such a way as to prevent excessive overswing. The extent to which the modern regulator approaches this ideal is shown by the oscillogram in figure 1. Notice that the regulator resistance becomes zero in less than two cycles, or about $^1/_{30}$ second after the load change occurs. This rapid response is made possible by new materials and a superior mechanical design which permit reduction of the inertia of the moving parts and of the inductance of the regulator coil.

A third requirement of any regulating mechanism, and by no means the least important, is that it be simple and highly reliable, and that it require a minimum of maintenance. Figures 2 and 3 show that these considerations have also had their part in the evolution of the modern regulator.

Paper 39-133, recommended by the AIEE committee on electrical machinery, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26-30, 1939. Manuscript submitted April 1, 1939; made available for preprinting May 4, 1939; released for final publication September 14, 1939.

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For their assistance in the preparation of this paper, the authors are especially indebted to R. W. Porter and C. Concordia.

Regulating System Assumed for Analysis

Figure 4 is a schematic drawing of the regulator and a connection diagram for the typical regulating system which is analyzed in this paper. The regulator operates by controlling the resistance in the shunt field circuit of the exciter in the following manner: The resistance presented by the regulator elements is varied in response to movement of the regulator armature. The position of the armature is determined by the balance between the torque of the spring and the electrical torque of the magnet. The current in the magnet coil comes from the a-c generator voltage through a rectifier. If the voltage drops, the current in the coil decreases, the armature changes position, and lowers the resistance in the exciter field until the voltage comes back to normal. The stabilizer, a simple iron-core transformer with an air gap, impresses in the regulator-coil circuit a transient voltage depending upon the change in generator field voltage. This transient voltage makes the regulator anticipate slightly the return of the alternating voltage to normal and thereby decreases the tendency to overswing or hunt.

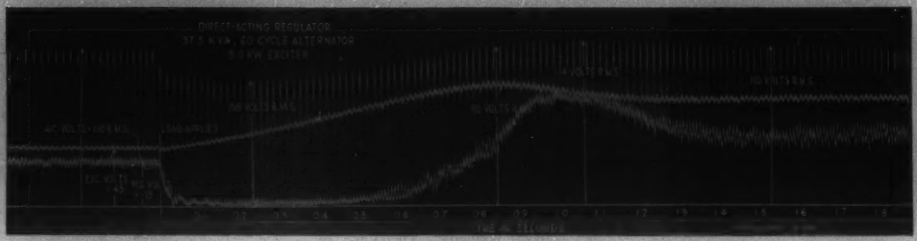
Method of Analysis

The tensor method of analysis, which is particularly well adapted for problems

pairs, as for example replacement of broken leads and caps to which reference is made in the paper.

The return on the investment in testing, and economic justification for such expenditure is probably questionable at least until the reliability of the testing methods is better established, and the loss of possible further years of service from unnecessarily rejected arresters is fully evaluated. The economic justification would also be questionable if repetitions of tests and cumulative expense for removals from service and testing over frequent intervals were necessary on the same arrester. More lasting economies would favor substitution by new arresters of modern design.

Herman Halperin: E. J. Allen has presented a critical discussion which should be stimulating to those interested in testing distribution arresters. Part of his remarks reiterate points made in the paper on shortcomings of the various simple tests in use, but in some places the criticism seems unwarranted and unsubstantiated by the experiences of utilities who have conducted tests. It is not certain that even the operating-duty test, which he emphasizes as all-important, will always eliminate an arrester which is in questionable physical condition. Detailed dissection of used arresters by utilities has disclosed a general correlation between observations and results of the tests which are made inexpensively with relatively simple apparatus. As to damage to the arresters by repeated 60-cycle tests, which should not occur with properly designed test circuits, the practices of utilities should not usually result in a given arrester's being installed and removed more than twice. The increasing number of utilities which find it desirable to test used arresters appears to justify the economic value of that practice. Further service experience with used arresters which were tested will be of immediate interest.



involving many elements, was used to set up the differential equations for small variations in the voltages, currents, torques, and angles of the regulating system. These equations were then examined to determine whether or not the variations tend to die away after a slight disturbance or to become larger with increasing time. In stable systems, the variations caused by any slight disturbance diminish to zero. But if any of the variations have a tendency to become larger, the system will not be in stable equilibrium at the operating point in question. This unstable condition is manifested by continued hunting or oscillating.

Any tendency for the variations to increase is evidenced by the existence of a positive real part in one or more of the roots of the characteristic denominator of the differential equations. Such a positive real part may be detected by the use of Routh's criterion.[1] In this manner regions of stable and unstable equilibrium were determined and factors which make for stability or instability investigated quantitatively.

General Conclusions

The more important results of this analysis can be briefly summarized as follows: It was found, for the typical system studied, that

1. In order to improve regulation

(*a*). The rate of change of regulator stack resistance with change in displacement should be large.

(*b*). The rate of change of regulator electrical torque with change in coil current should be large.

(*c*). The difference between the rates of change of electrical torque and of mechanical torque with respect to regulator-armature mechanical displacement should be small.

(*d*). The difference between the rates of change of exciter armature voltage and of exciter field circuit IR drop with respect to exciter field current should be small.

(*e*). The rate of change of regulator stack resistance with change in current should be negative.

2. In order to improve the stability

(*a*). The factors listed in conclusion 1 should be changed in the opposite direction to that required for improving the regulation.

1. For all numbered references, see list at end of paper.

Figure 1. Oscillogram showing response of direct-acting regulator

"Exc. Volts" is measured across the exciter armature

"Reg. Volts" is measured across the regulator rheostat

Alternator originally at no load; 19.0 kva, 0.3 power factor load applied

(*b*). The moment of inertia of all the movable parts of the regulator should be reduced.

(*c*). The exciter field inductance should be increased.

3. With reduction in the moment of inertia, the factors which influence the regulation have less influence on the stability; therefore they can be changed in the direction to improve the regulation without impairing the stability as much as would be the case with a higher moment of inertia.

4. In the region of low exciter saturation, perfect regulation, or even a slightly rising voltage characteristic with load can be obtained with stability.

The analytical results are in agreement with present laboratory and field experience. Accordingly the method presented is a dependable means by which the effects of the various influencing factors on a regulating system may be analyzed and knowledge of regulating systems be extended.

Discussion

Grouping of Constants

In analyzing the regulating system it was possible to group many of the circuit constants together in order to simplify the analysis and help provide a clear physical concept. Two important factors in the operation of the system, both from a stability and regulation standpoint, are designated by the terms R_D and X_D, which have been called exciter stability factor and regulator stability factor, respectively.

R_D is the difference between the effective resistance of the exciter field circuit to small current changes, and the ratio of the change in generated voltage of the exciter to the corresponding small change in exciter field current. Referring to figure 5, OS is the exciter saturation curve measuring the variation of exciter generated voltage with field current, and the line OA is the exciter-field-circuit resistance line for a particular position of the regulator. The curvature of this line comes from the nonlinear characteristic of the resistance used in the regulator. The line ss' is tangent to the curve OS at the operating point P; aa' is tangent to the curve OA. The greater the difference between the slopes of aa' and ss', the less susceptible the exciter voltage is to slight changes in resistance. Accordingly, the difference of these slopes can be considered as a measure of the stability of the exciter. Such a concept is well-known.

The characteristic of the regulator resistance is such that its effective resistance decreases with increase in current. As shown by figure 5, this characteristic tends to make curve OA ap-

Figure 2. Direct-acting voltage regulator with enclosing case

proach OS in shape thereby reducing the difference between the slopes of aa' and ss', and making this difference more uniform over the operating range. If the resistance curve is sufficiently non-linear, the difference of the slopes may be slightly negative, $-R_D$. Although the exciter by itself may be unstable under this condition, the corrective action of the regulator and stabilizer can overcome this instability and produce stable operation of the system. In fact, a uniformly low or negative value of R_D is desirable as a means of improving the regulation.

X_D, the regulator stability factor, is the difference between the rate of change of spring torque acting on the regulator armature and the corresponding rate of change of electrical torque for a given small change in mechanical displacement. See figure 6.

If the regulator armature is to be at equilibrium in any particular position, the electrical torque must just overcome the spring torque at that position. Now if the armature is moved by some external torque in the same direction as the magnetic torque, the spring will be further stressed and its force will increase slightly. Even though the alternating voltage from which the coil is magnetized remains constant during this process, the magnetic force may increase or decrease depending on the shape of the armature and pole tips. If the magnetic force decreases, or, as in figure 6, increases less rapidly than the opposing spring force, the armature will be urged back to its initial position. Such an equilibrium is commonly called stable equilibrium. But if the magnetic force increases more rapidly than the spring force, the armature will be urged away from its initial position, and the operating point will be a point of unstable equilibrium. Thus X_D, the difference between the rate of increase of the spring torque and of the electrical torque, is a measure of the stability of the regulator armature.

The more positive this quantity, X_D, becomes, the less sensitive the armature will be to a given change in electrical torque. Therefore X_D is inversely proportional to the amplification of the mechanical part of the regulator just as R_D is inversely proportional to the amplification of the exciter.

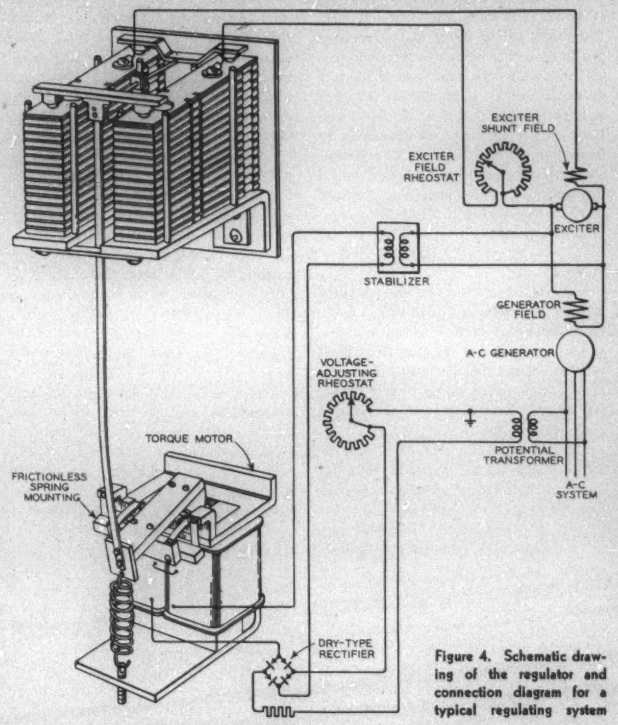


Figure 4. Schematic drawing of the regulator and connection diagram for a typical regulating system

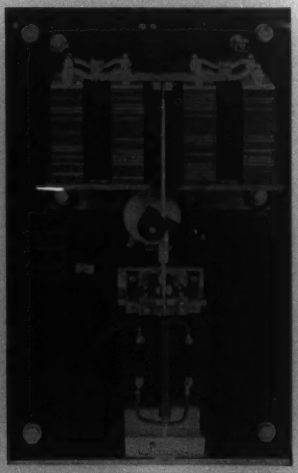


Figure 3. Direct-acting voltage regulator with enclosing case removed, showing operating mechanism

Regulation

The regulation of a system, which is a measure of its ability to hold the regulated quantity at a constant value, is a function of what has been termed in the analysis the over-all amplification factor. This factor can be defined as the ratio of the change in the terminal voltage of the a-c machine to an arbitrary small change in the alternating voltage applied to the regulator. It normally has a negative sign, for when the voltage applied to the regulator is high, the regulator tends to reduce the alternator terminal voltage.

The total amplification factor of the system is the product of the amplification factors of the various elements which may be considered as constituting stages of amplification. This is readily visualized by consideration of figure 7 which shows schematically the different elements of the system as stages of amplification and the corresponding mathematical expressions which define their respective amplification factors.

The amplification may be very large, theoretically equal to infinity, if either the regulator stability factor, X_D, or the exciter stability factor, R_D, are equal to zero. This indicates that flat regulation can be obtained if the exciter or regulator is operated at a point where

it would approach instability by itself. The amplification factor may even be a positive number, which corresponds to a rise in voltage with increase in load, if either R_D or X_D is negative. Whether it is positive or negative, the amplification factor is increased in magnitude by increasing the rate of change of regulator stack resistance with armature mechanical displacement, or by increasing the rate of change of electrical torque with regulator-coil current.

Stability

The regulator and exciter stability factors, R_D and X_D, are two of the most important factors which influence stability. They are also the two which can be varied most easily. For this reason, they were chosen as ordinates for the curves which show the results of the stability analysis.

Figure 8 shows the effect of a stabilizer for a typical set of conditions with the regulator moment of inertia neglected (assumed equal to zero). The abscissa is X_D, the regulator stability factor; the ordinate is R_D, the exciter stability factor. Curve A shows that over-all stable operation will exist without a stabilizer in the region of low exciter stability if X_D is large. However, as R_D can be expected to vary appreciably with exciter saturation over the range of loads and with field temperature, good over-all regulation must be obtained by making X_D small also. Curve B shows that if a stabilizer is used, stable operation can be maintained with small values of both X_D and R_D. Thus the effect of the stabilizer is clearly shown in compensating for regulator instability and in making possible good regulation with stable operation over the range which R_D may take. By design practice, the operating point is kept well within the stable regions in order that all oscillations will decay rapidly.

The effect of variation in the regulator moment of inertia is shown in figure 9, other conditions remaining the same as for figure 8, curve B. These curves show very clearly that the smaller the moment of inertia of the regulator, the greater the stability. As the moment of inertia does not affect the regulation, it should be made as small as possible. By so doing improved regulation can be obtained, without instability.

Figure 10 shows the effect on stability when the rate of change of regulator resistance with armature displacement is increased four times for a given set of conditions. This comparison shows that from the viewpoint of stability alone it appears desirable to make the rate of change small. Notice, however, that a given increase in the rate of change does not require a proportional increase in X_D for stability. On the other hand, the amplification factor, which determines the regulation, is directly proportional to the ratio of the rate of change of resistance to X_D. Therefore, a net improvement in regulation can be obtained without affecting the stability by increasing both the rate of change of regulator resistance with displacement and the value of X_D.

Figure 11 shows the effect of changing the exciter-field inductance, all other factors remaining the same. These curves indicate that a system is more likely to be stable if the exciter-field time constant is large, but this condition is contrary to the requirement of rapid response. Consequently, increase of exciter-field time constant is not in general a practical method for improving stability.

Analysis

Assumptions

In order to adapt this investigation to mathematical analysis certain assumptions were made, the most important of which are the following:

1. Displacements are of small magnitude.
2. The alternator speed is constant.
3. The alternator load is purely reactive. Reactive loads usually cause the most severe regulation.
4. Voltages due to rates of change of flux linkages are small compared to voltages due to rotation of the machine.
5. The exciter speed is constant.
6. Friction in the movable parts of the regulator is negligible. Friction is kept as small as possible on most regulators for mechanical reasons.
7. At the operating point the rectifier develops changes in direct voltage proportional to changes in the fundamental alternating voltage less a linear resistance drop.

Both regulation and stability were studied on the basis of the above assumptions. This work indicated that it was reasonable to make further assumptions in the study of stability. These further assumptions were:

1. The alternator is at no load.
2. Stabilizer magnetizing current is negligible.

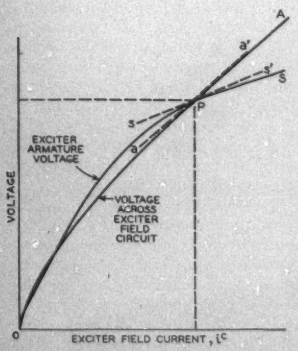


Figure 5 (left). Illustration of R_D, exciter stability factor

R_D = slope aa' minus slope ss'

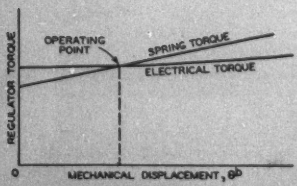
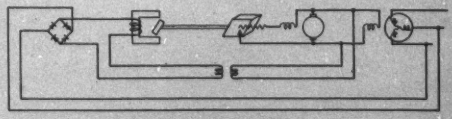


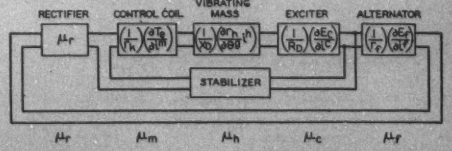
Figure 6 (left). Illustration of X_D, regulator stability factor

X_D = slope of spring torque curve minus slope of electrical torque curve

Figure 7. Stages of amplification and over-all amplification factor

$$\mu_o = \frac{\mu_r \left(\frac{\partial T_e}{\partial i^m}\right)\left(\frac{\partial r_h}{\partial \theta^n}\right)^{th}\left(\frac{\partial E_c}{\partial i^c}\right)\left(\frac{\partial E_f}{\partial i^f}\right)}{r_k X_D R_D r_f}$$





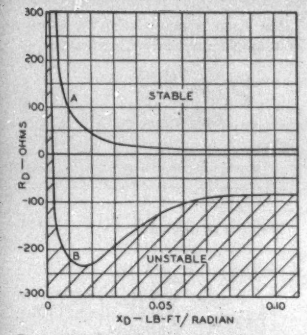


Figure 8. Excitation-system stability characteristics showing effect of stabilizer. Regulator moment of inertia neglected (assumed equal to zero)

Alternator rating 37.5 kva, 110 volts, 60 cycles

A—No stabilizer *B*—With stabilizer

3. Exciter armature resistance is negligible.
4. Exciter armature inductance is negligible.

The point at which these additional assumptions are introduced is indicated in the analysis.

NOMENCLATURE

Particular values of the following quantities are identified by appropriate superscripts.

i—current
θ—angle of displacement from a given position

Particular values of the following quantities are identified by appropriate subscripts.

m—moment of inertia
e—voltage
r—resistance
ψ—flux linkages
$L=\partial\psi/\partial i$—incremental self-inductance
$M=\partial\psi/\partial i$—incremental mutual inductance
E—generated voltage due to rotation relative to flux in line with field poles
μ—amplification factor of an element of the regulating system

The following symbols are used as subscripts or superscripts.

m—regulator coil
h—regulator rheostat
b—regulator armature
g—rheostat operating arm
c—exciter field
a—exciter armature
f—alternator field
d—alternator direct axis[2]
q—alternator quadrature axis[2]
r—rectifier
p—primary of stabilizer (connected to exciter armature)
s—secondary of stabilizer (connected into regulator circuit)
k—regulator-coil circuit (rectifier, stabilizer secondary, and regulator coil) under steady-state conditions
T—regulator-coil circuit of the interconnected system under oscillatory conditions

When not identified by a subscript:

$m=m_b+m_g$=total moment of inertia of movable parts of the regulator

The following quantities also appear in the analysis:

T_e—electrical torque on regulator armature
T_Σ—spring torque on regulator armature
μ_0—over-all amplification factor
n—ratio of $\dfrac{\text{primary turns}}{\text{secondary turns}}$ of stabilizer

It should be noted that resistances, inductances, and flux linkages of the stabilizer are referred to the primary.

$$R_D=-\frac{\partial E_c}{\partial i^c}+r_h+r_c+\frac{\partial r_h}{\partial i^c}i^c+r_a,$$

the exciter stability factor.

$$X_D=\frac{\partial T_\Sigma}{\partial\theta^b}-\frac{\partial T_e}{\partial\theta^b},$$

the regulator stability factor.

In the tensor notation, each unit vector is designated in bold-face type by the same symbol which is used as a superscript for the current (or angle) of the circuit to which the unit vector applies.

A prime (′) identifies terms applying to the system after interconnection.

A double prime (″) identifies terms applying to the interconnected system after introduction of the assumption that stabilizer magnetizing current is negligible.

DERIVATION OF EQUATIONS

The following presents the development of the equations from which the performance of the system (figure 13) was determined. Using the tensor method of attack,[2] the first step was to set down the equations for the individual parts of the system shown in figure 12; second, by means of the connection tensor, the equations applying to the interconnected system were

Figure 9. Excitation-system stability characteristics showing effect of change in regulator moment of inertia. Effect of stabilizer included

Alternator rating 37.5 kva, 110 volts, 60 cycles

A—$m=0$

B—$m=7.37\times10^{-6}$ pound-feet-seconds²/radian

C—$m=73.7\times10^{-6}$ pound-feet-seconds²/radian

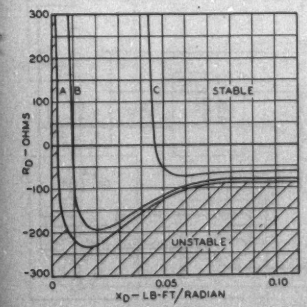


Figure 10. Excitation-system stability characteristics showing effect of change in the rate of change of regulator rheostat resistance with regulator displacement

Alternator rating 37.5 kva, 110 volts, 60 cycles

A—$\dfrac{\partial r_h}{\partial\theta^g}i^c=40.7$ volts per radian

B—$\dfrac{\partial r_h}{\partial\theta^g}i^c=162.5$ volts per radian

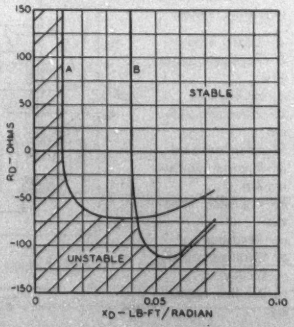
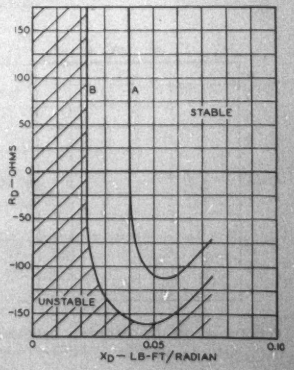


Figure 11. Excitation-system stability characteristics showing effect of change in exciter field inductance

Alternator rating 37.5 kva, 110 volts, 60 cycles

A—$L_c=30$ henries *B*—$L_c=60$ henries



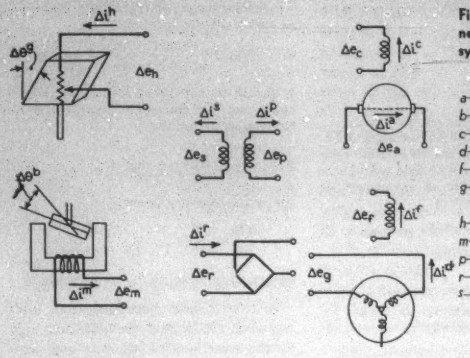


Figure 12. Component parts of regulating system before interconnection

a—Exciter armature
b—Regulator armature
c—Exciter field
d—Alternator armature
f—Alternator field
g—Rheostat operating arm
h—Regulator rheostat
m—Regulator coil
p—Stabilizer primary
r—Rectifier
s—Stabilizer secondary

found; third, the determinant of the equations for the currents and angular displacements was found; and fourth, Routh's criterion[1] was applied in order to determine the necessary conditions for stable operation. Routh's criterion is an algebraic rule, the application of which is discussed later in this analysis.

1. *General Equations Before the Interconnection*

The equations for the component parts may be summarized by the equation of small changes

$$\Delta \boldsymbol{e} = \boldsymbol{z} \cdot \Delta \boldsymbol{i} \tag{1}$$

where the impedance tensor, $\boldsymbol{z}$, of the component parts is given in equation 2.

2. *Equations for the Connected System*

When the parts are connected together as shown in figure 13, the effect of the interconnection may be represented by transformation of the tensor, $\boldsymbol{z}$, according to the equation

$$\boldsymbol{z}' = \boldsymbol{C}_t \cdot \boldsymbol{z} \cdot \boldsymbol{C} \tag{3}$$

where

$$\boldsymbol{C} = \begin{array}{c|cccccc} & c' & f' & p' & m' & b' & d' \\ \hline m & & & & 1 & & \\ b & & & & & 1 & \\ h & 1 & & & & & \\ g & & & & & 1 & \\ c & 1 & & & & & \\ a & 1 & 1 & 1 & & & \\ f & & 1 & & & & \\ r & & & & 1 & & \\ d & & & & & & 1 \\ p & & & 1 & & & \\ s & & & & -1 & & \end{array} \tag{4}$$

Performance of the operations indicated in (3) yields equation 5.

3. *Regulation*

If the regulator were inoperative, a change, Δe_g, in alternator terminal voltage would not result in any change, Δi^f, in alternator field current or corresponding change $(\partial E_f/\partial i^f)\,\Delta i^f$, in internal generated voltage. The effectiveness of the regulator may be expressed in terms of its ability to cause a change $(\partial E_f/\partial i^f)\,\Delta i^f$, in response to a change, Δe_g.

At steady state ($p = 0$), solution of equation 5 yields

$$\frac{\partial E_f}{\partial i^f}\Delta i^f = \mu_\theta \Delta_{eg} \tag{6}$$

where the steady-state amplification factor,

$$\mu_\theta = \frac{-\mu_r \dfrac{\partial E_f}{\partial i^f}\cdot\dfrac{\partial T_e}{\partial i^m}\left(\dfrac{\partial E_c}{\partial i^c}-r_a\right)\dfrac{\partial r_h}{\partial \theta^g}}{\left(r_m+r_r+\dfrac{r_s}{n^2}\right)X_D\left[R_D+r_a\left(1+\dfrac{r_f}{r_p}\right)\dfrac{\dfrac{\partial E_c}{\partial i^c}-r_a}{r_f+r_a\left(1+\dfrac{r_f}{r_p}\right)}\right]\left[r_f+r_a\left(1+\dfrac{r_f}{r_p}\right)\right]} \tag{7}$$

For $r_a = 0$, equation 7 for the steady-state amplification factor, becomes

$$\mu_\theta = -\frac{\dfrac{\partial r_h}{\partial \theta^g}\dfrac{\partial T_e}{\partial i^m}\mu_r\dfrac{\partial E_f}{\partial i^f}\dfrac{\partial E_c}{\partial i^c}}{R_D X_D r_f r_k} \tag{8}$$

where

$$r_k = r_m + r_r + \frac{r_s}{n^2}$$

This may be written as

$$\mu_\theta = -[\mu_r]\left[\left(\frac{1}{r_k}\right)\left(\frac{\partial T_e}{\partial i^m}\right)\right]\times\left[\left(\frac{1}{X_D}\right)\left(\frac{\partial r_h}{\partial \theta^g}\right)\right]\left[\left(\frac{1}{R_D}\right)\left(\frac{\partial E_c}{\partial i^c}\right)\right]\times\left[\left(\frac{1}{r_f}\right)\left(\frac{\partial E_f}{\partial i^f}\right)\right] \tag{9}$$

$$= -\mu_r\mu_m\mu_h\mu_c\mu_f$$

where the μ's are the amplification factors of the various stages (see figure 7).

It may be seen that, in general, each amplification factor consists of a self-admittance times a mutual impedance. The effect on regulation of changes in any of the system constants can thus readily be visualized in terms of their effect on these admittances and impedances.

4. *Stability*

Equation 5 defines the system of differential equations which apply to the departures, Δi, from steady-state values of the currents (and angle) of the connected system after any slight disturbance. The solutions of this system

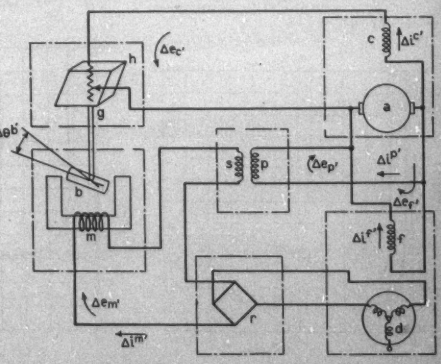


Figure 13. Diagram of interconnected regulating system

a—Exciter armature
b—Regulator armature
c—Exciter field
d—Alternator armature
f—Alternator field
g—Rheostat operating arm
h—Regulator rheostat
m—Regulator coil
p—Stabilizer primary
r—Rectifier
s—Stabilizer secondary

	m	b	h	g	c	a	f	r	d	p	s
m	$r_m+L_m\dot{p}$	$\frac{\partial\psi_m}{\partial\theta^b}\dot{p}$									
b	$\frac{\partial T_\epsilon}{\partial i^m}$	$\frac{\partial T_\epsilon}{\partial\theta^b}-\frac{\partial T_\Sigma}{\partial\theta^b}-m_b\dot{p}^2$									
h			$r_h+\frac{\partial r_h}{\partial s^h}s^h+\frac{\partial r_h}{\partial\theta^g}s^h$								
g			0	$-m_g\dot{p}^2$							
c					$r_c+L_c\dot{p}$	0					
$z=a$					$-\frac{\partial E_c}{\partial i^c}$	$r_a+L_a\dot{p}$					
f							$r_f+L_f\dot{p}$	0	$M_{fd}\dot{p}$		
r							$-\mu_r\frac{\partial E_f}{\partial i^f}$	r_r	$-\mu_r\frac{\partial E_f}{\partial s^d}$		
d							$-\frac{\partial E_f}{\partial i^f}$	0	$-\frac{\partial E_f}{\partial s^d}$		
p										$r_p+L_p\dot{p}$	$\frac{1}{n}M_{sp}\dot{p}$
s										$\frac{1}{n}M_{sp}\dot{p}$	$\frac{1}{n^2}r_s+\frac{1}{n^2}L_s\dot{p}$

(2)

of equations express the values of these departures as functions of time. These functions of time consist of the real parts of a series of terms of the form

$$Ae^{\alpha t} \tag{10}$$

where A is an arbitrary constant and α is in general a complex number. α is always a root of the algebraic equation in powers of $\dot{p}$ formed by setting equal to zero the determinant of the system of equations defined by equation 5. This determinant is

$$D=a_8\dot{p}^8+a_7\dot{p}^7+a_6\dot{p}^6+a_5\dot{p}^5+a_4\dot{p}^4+a_3\dot{p}^3+a_2\dot{p}^2+a_1\dot{p}+a_0 \tag{11}$$

where the a's are determined by the constants of the system.

If the real part of the complex number, α, is positive, the term, $Ae^{\alpha t}$, increases with increasing time. This means that after a slight disturbance the currents do not tend to return to their steady-state values, but increase until the departures, Δi, are so large that they become limited by saturation or some other change in the system constants. Hence, the system is defined as being unstable if the real part of any root, α, of the determinant (11) is positive.

The existence of a root having a positive real part may be detected by the use of Routh's criterion without actual solution for the roots of the determinant (11). Routh's criterion depends upon the relative values of the a's of (11) and, in general, requires the substitution of numerical values for the system constants which determine the values of the a's. The effect of varying system constants may be found by trial.

Use of Simplifying Assumptions

It has been found possible to simplify the analysis of stability by making certain assumptions which appear reasonable.

(a). The alternator load current, i^d, may be assumed to be zero, since experience has shown that in general the system is more stable when the generator is loaded than at no load.

(b). Calculations on stability of typical systems have indicated that it is justifiable

	c'	f'	p'	m'	b'	d'
c'	$r_h+\frac{\partial r_h}{\partial i^h}i^h+r_c+r_a-\frac{\partial E_c}{\partial i^c}+(L_a+L_c)\dot{p}$	$r_a+L_a\dot{p}$	$r_a+L_a\dot{p}$	0	$\frac{\partial r_h}{\partial\theta^g}s^c$	0
f'	$r_a+L_a\dot{p}-\frac{\partial E_c}{\partial i^c}$	$r_a+r_f+(L_a+L_f)\dot{p}$	$r_a+L_a\dot{p}$	0	0	$M_{fd}\dot{p}$
$z'=p'$	$r_a+L_a\dot{p}-\frac{\partial E_c}{\partial i^c}$	$r_a+L_a\dot{p}$	$r_a+r_p+(L_a+L_p)\dot{p}$	$-\frac{1}{n}M_{sp}\dot{p}$	0	0
m'	0	$-\mu_r\frac{\partial E_f}{\partial i^f}$	$-\frac{1}{n}M_{sp}\dot{p}$	$r_m+r_r+\frac{1}{n^2}r_s+\left(L_m+\frac{1}{n^2}L_s\right)\dot{p}$	$\frac{\partial\psi_m}{\partial\theta^b}\dot{p}$	$-\mu_r\frac{\partial E_f}{\partial s^d}$
b'	0	0	0	$\frac{\partial T_\epsilon}{\partial i^m}$	$\frac{\partial T_\epsilon}{\partial\theta^b}-\frac{\partial T_\Sigma}{\partial\theta^b}-(m_b+m_g)\dot{p}^2$	0
d'	0	$-\frac{\partial E_f}{\partial i^f}$	0	0	0	$-\frac{\partial E_f}{\partial s^d}$

(5)

to neglect stabilizer magnetizing current. The effect of this assumption may be represented by the equation

$$s' = C_i' \cdot s' \cdot C' \tag{12}$$

where

$$C' = \begin{array}{c|cccc} & c' & f' & m' & b' \\ \hline c' & 1 & & & \\ f' & & 1 & & \\ m' & & & 1/n & \\ b' & & & 1 & \\ & & & & 1 \end{array} \tag{13}$$

(c). Calculations for typical systems have indicated that it is justifiable to make the further simplifying assumptions that exciter armature resistance, r_a, and exciter armature inductance, L_a, are zero.

On the basis of the assumptions of (a), (b), and (c), equation 5 becomes

$$s' = \begin{array}{c|cccc} & c' & f' & m' & b' \\ \hline c' & R_D + L_c p & 0 & 0 & \frac{\partial r_h}{\partial \theta^2} i^c \\ f' & -\frac{\partial E_c}{\partial i^c} & r_f + L_f p & 0 & 0 \\ m' & -\frac{1}{n}\frac{\partial E_c}{\partial i^c} & -\mu_r \frac{\partial E_f}{\partial i^f} & r_T + L_T p & \frac{\partial \psi_m}{\partial \theta^2} p \\ b' & 0 & 0 & \frac{\partial T_e}{\partial i^m} & -X_D - mp^2 \end{array} \tag{14}$$

where

$$r_T = \frac{r_p + r_s}{n^2} + r_m + r_r$$

$$L_T = \frac{\partial \psi_m}{\partial i^m} + \frac{1}{n^2}(L_a + L_s + L_p - 2M_{sp})$$

The determinant of equation 14 is

$$\text{Det.} = b_4 p^4 + b_3 p^3 + b_2 p^2 + b_1 p + b_0 \tag{15}$$

where the b's are functions of the resistances, inductances, and other physical constants of the system.

If the physical constants of a system are known, stability may be studied by applying Routh's criterion to the b's of (15) in the same manner in which it was applied to the a's of (11). For the special case, m is zero, $b_4 = 0$, and $b_4 = 0$.

From calculations of this sort the stability characteristics shown in figures 8, 9, 10, and 11 were determined.

Summary

The major factors involved in the design and application of the direct-acting regulator and their relation to each other have been discussed. An outline has been presented of the mathematical method by which these relations were derived. Finally it has been shown that the modern direct-acting regulator, when properly designed for the system in which it must function, satisfies all the fundamental requirements of a regulating system.

References

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2. Two-Reaction Theory of Synchronous Machines—Generalized Method of Analysis—Part I. R. H. Park. AIEE Transactions, volume 48, July 1929, pages 716–27.

3. Tensor Analysis of Networks (a book). Gabriel Kron. John Wiley and Sons, Inc., New York, 1939.

The Application of Tensors to the Analysis of Rotating Electrical Machinery, Parts I–XVI (a book). Gabriel Kron. *General Electric Review*, 1938.

Discussion

F. E. Crever (General Electric Company, Schenectady, N. Y.): The system analyzed in this paper is by far the most usual in which the direct-acting regulator is employed and hence the very thorough analysis made is of particular interest. The use of the direct-acting regulator is of course not limited to such a system. A great many of the direct-acting-regulator applications have been made to regulate not only voltage but current, speed, torque, tension, and other quantities both in the central-station field and in industrial plants. The outstanding problem in such applications is to obtain stability and good regulation together. As the paper points out, a great many of the factors that favorably influence regulation have a tendency to decrease the stability. In general the method of analysis employed by the authors can be applied to any regulating system. The tensor method is particularly applicable in that it allows the equations of the component parts of the system to be set up and then to be readily combined to represent a complex system. The characteristic denominator of the system of differential equations is usually of a high degree so that simplifying assumptions are necessary to obtain a ready solution. The authors have been very careful in the assumptions made, which accounts for the good agreement between the analysis and practical results.

C. Concordia (General Electric Company, Schenectady, N. Y.): There are two points in this paper which I should like to amplify.

First we note that it is stated that the exciter-field inductance should be increased to improve stability. Since some investigators have concluded that all time lags in the amplification stages should be as small as possible for stability, it is of interest to comment on this conclusion. Study of the performance equations shows that the reason a certain amount of lag may be desirable is the presence of mutual terms (that is, mutual reactions between various stages) in addition to the components of the amplification factor, or the presence of second order lags (for example, the regulator-armature inertia). The mutual reactions may arise either from the stabilizer or from inherent mutual effects.

These considerations bring out the importance of studying the actual system equations, as was done in this paper, rather than an idealized system in which some of the mutual effects may be left out.

A second point to be commented on is the effect of friction in the regulator armature. It is evident that friction must be small if the regulator stability factor X_D is to be made very small. Moreover, calculations show that such friction (treated as viscous damping) is detrimental to stability and thus indicate an additional advantage of minimizing the regulator friction. Figure 4 shows one well-known mounting for accomplishing this result. Regulator friction was introduced into a system having nearly the constants of figure 9 of the paper, with results as follows:

D	M	R_D	X_D
0	0	0	0.003
0.0022	0	0	0.026
0	0.0000737	0	0.028
0.0022	0.0000737	0	0.031

where

D is the damping coefficient and $D = 0.0022$ is about one-half the value required for critical damping with $X_D = 0.09$.

M is the regulator-armature inertia.

R_D is the exciter stability factor, taken as zero in this case.

X_D is the minimum value of regulator stability factor required for stable operation.

C. E. Valentine (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors have developed an interesting analysis of a regulating system. Except for the mathematical treatment by means of the tensor method, which appears more complicated than simple to many engineers, the assumptions made and conclusions reached are, in general, quite in line with operating experience.

Of particular interest is one of the general conclusions (2b) that in order to improve stability, the moment of inertia of all the movable parts of the regulator should be reduced. This has been recognized for some time as a fundamental feature of a direct or indirect-acting type of regulator. In the "Silverstat" regulator described in AIEE Paper 39-91 (AIEE Transactions, volume 58, 1939, pages 838–44) a lightweight quick-acting moving arm was used even in the earliest design.

This same feature has been used consistently on all later designs which have also achieved an enviable record of performance both on single generators and generators in parallel.

The adoption of the crossed-leaf type spring mounting (also described in the earlier paper) for the moving element and the extension of this idea in the form of a spring for actuating the variable-resistance member, as shown schematically in figure 4, is a desirable improvement over the bearings and linkage previously used. The crossed-

spring type of hinge has a background of most satisfactory performance as the supporting means for the moving arm on the Silverstat generator voltage regulators where it has been used from the start.

K. A. Oplinger (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors have pointed out the possibility of using a nonlinear resistance characteristic in a regulator as a means of improving regulation. It would appear difficult to make this nonlinear characteristic such that the slope of the exciter-field-circuit resistance line always approaches the slope of the exciter saturation curve. I would like to ask if it has been practical to do this for all types of exciters, and if so, what actual improvement in regulation is secured taking into account that R_D will change appreciably with exciter saturation and field temperature?

The general conclusions of the authors under (2c) state that the exciter field inductance should be increased in order to improve stability. Since this conclusion is not in agreement with experimental results, could not this conclusion be in error due to assumptions made regarding the size of the stabilizer?

C. R. Hanna (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The accuracy of a voltage regulator is determined by the over-all amplification factor of the system which is the ratio of the change in generated voltage to the deviation in terminal voltage. The authors give the equation for the amplification of their regulator at the bottom of figure 7 of their paper. It would have been more instructive if data on system stability had been given in terms of the amplification instead of just the X_D and R_D factors which as indicated in their equation, only partially determine the amplification.

The curves given show only the limiting conditions for stable operation. No computations are made of damping conditions corresponding to points in the stable range. It is necessary to have large decrements of any system oscillations so that disturbances due to load changes, etc., will not cause continuous swinging of the voltage. Points in the stable range may not be selected indiscriminately because the damping may still be too low for practical operation.

In the interests of simplifying a problem as involved as that of voltage regulation, many variables have to be eliminated or assumed to have a small influence. The authors make one assumption, however, which is difficult to justify; namely, that the stabilizer magnetizing current is zero. This means infinite self- and mutual inductance and, therefore, a transformer of infinite size. Such an assumption completely ignores the problem of determining just how large the stabilizer should be for a good practical result.

The mathematical processes used in the paper could have been employed to yield much more design information than is given. One is somewhat disappointed that the numerical results do not include such pertinent information as rates of decay of oscillations or methods of predicting transformer size for a given system. As shown in the recent paper by the writer and his collaborators on "Recent Developments in Voltage Regulation" (AIEE TRANSACTIONS, volume 58, 1939, pages 838–44) these can be computed by less involved processes than the method of tensors as used by the authors.

W. K. Boice, S. B. Crary, Gabriel Kron, and L. W. Thompson: Mr. Hanna suggests that simpler methods could be used which would yield more easily the damping factors. The equations in the paper can be simplified to almost any extent by making assumptions or neglecting the effect of certain factors so that they will yield the damping factors directly, or with little numerical work. This is usually accomplished at a sacrifice of accuracy and, what is more important, at a sacrifice of the ability to determine the effect of factors which influence the regulator and excitation-system design. In many cases, it is advisable to make simplifying assumptions only after a more general approach has been made. In this way the simplifying assumptions may be tested for validity.

Mr. Hanna questions the validity of neglecting stabilizer magnetizing current. The calculations which we have made for a typical system have indicated that this could be done with small error. However, the influence of stabilizer magnetizing current was studied and can be further studied by using the corresponding more general equations presented in the paper.

Mr. Oplinger questions the value of the nonlinear stack-resistance characteristic in that it would be difficult in practice to have the exciter characteristic slope always correspond to the field circuit resistance line. It is not necessary and is practically impossible that these characteristics correspond for all loads. However, the nonlinear stack resistance for any given load condition results in better regulation than a linear-characteristic regulator-stack resistance. It is in the direction to improve the regulation and is accordingly desirable from this standpoint.

For the typical system which we have studied, the analysis showed that an increase in field inductance improved stability. This would not necessarily be true for any system, particularly one whose constants or connections deviated materially from those chosen for study. However, experience with direct-acting regulators over a period of years has indicated for a wide range of typical systems that increased exciter field inductance is in the direction to improve stability.

Mr. Concordia's comments and contributions on regulator friction are appreciated and can be considered a valuable addition to the material presented in the paper.

We are pleased to learn from Mr. Valentine that he has also found the crossed-spring type of hinge and low moment of inertia to be most satisfactory. This type of design has definite advantages.

We wish to thank Mr. Crever for emphasizing that the method presented in the paper may be used for other types of regulating systems.

Signal System, Interlocking Plants, and Automatic Train Control on the San Francisco-Oakland Bay Bridge Railway

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Synopsis: This paper briefly describes the nature and purpose of the various groups of railway signal and interlocking equipment operated in connection with railway service over the San Francisco-Oakland Bay Bridge. Following this description is an explanation of the method used in determining the lengths of signal blocks and calculating safe braking distances throughout the project. It is hoped that the presentation of this paper will lead to further discussion and research concerning the braking of trains of this type.

THIS eight-mile-long double-track railway with its "train-a-minute" operation called for the most complete and modern system of block signalling and train control, and required the maxmium facility for operating the switches and wayside signals at the San Francisco terminal, at the Oakland yard, and at the junction of the two railways. The means by which these extreme requirements were met, the choice throughout of electrical equipment in preference to nonelectrical mechanical devices, the design of an electromechanical "brain" consisting of 3,000 relays with their interlocking circuits, the certain and safe solution of new and unique circuit problems, comprise the history of the installation. Signal blocks are here, but no signals are visible along the tracks. Instead, there is a four-speed signal in the cab directly before the eyes of the motorman. Should the train exceed the speed indicated, an automatic brake application brings the train to a stop. The method used for the calculation of safe braking distances and the determination of suitable block lengths may interest those who are confronted with similar problems.

An interlocking control machine at which the operator merely pushes two buttons on a track diagram to set up a route, position the switches, and clear the signals, automatically and infallibly avoids the authorizing of any conflicting or unsafe move. If, for any reason, the customary or preferred route between the two points is not available, the machine will unerringly select and set up another route, if any be available, between the two points. On these same control boards are the operating buttons and indication lights of a system for the transmission, reception, and storage of the identities of trains of the 15 lines of the Oakland and Berkeley network. In each tower, one in San Francisco and one in Oakland, the operator has at all times a visible picture of the trains approaching on the bridge, and the identity of the nearest three is always shown.

Paper 39-138, recommended by the AIEE committee on transportation, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939. Manuscript submitted April 19, 1939; made available for preprinting May 18, 1939; released for final publication August 16, 1939.

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Cab-Signal and Train Control System

The system is a true automatic block system with double-rail track circuits, using reactance or impedance bonds at the insulated joints to provide a path for the negative return of the power current, but having no visible block signals whatsoever. Instead of semaphore arms automatically taking various angles, the 100-cycle signal current in the rails is uniformly interrupted, the rate of interruption in each block depending on its distance behind the occupied block. A clear track ahead is denoted by 180 interruptions per minute, occupancy less than "clear track" distance by 120 interruptions per minute, occupancy in the second block ahead by 75 per minute. Occupancy in the first block ahead or in the immediate block is denoted by a steady current or by no current. Receivers at the front end of the train pick up the signal current by induction, filtering and amplifying it, and the interruption rate picks up the corresponding rate relay on the train, thereby selecting the cab-signal light and the set of governor contacts which will remain in control so long as that code continues to be picked up.

Whenever the train reaches the authorized speed as indicated by the cab signal, a white light is lighted, and remains lighted as long as the speed equals or exceeds that indicated. Should the speed be increased until it is one mile per hour greater than that authorized, a warning signal sounds and continues sounding until the speed is reduced below that point. Should the train continue to accelerate and reach a speed two miles in excess of that authorized, an immediate emergency brake application will automatically result and the train is brought to a full stop. When the cab-signal aspect changes to indicate a lower speed, and the train is not already down to this new authorized speed, the motorman is allowed $2^1/_2$ seconds in which to initiate a service-brake application which he must hold until the train is down to the authorized speed. Any delay beyond that period will cause an automatic emergency application of the brakes and the train will be brought to a full stop. When the aspect changes to the lowest-speed indication, the motorman, in addition, must step on an "acknowledging contact" pedal for, though he may be traveling below that speed and consequently not be required to apply the brakes, he must indicate that he is alert and prepared to stop in case the block ahead is occupied.

The designed arrangement of codes and controls is given in table I.

An additional code of 240 interruptions per minute, used at points where trains leave cab-signaled tracks, cancels the cab-signal and train-control equipment on the train, lights a violet light in the cab signal showing the letters "NS", and permits the train to proceed without speed restrictions until a control code is again encountered.

In such an automatic block system the controls are set up by the occupancy or nonoccupancy of a track block. The 100-cycle current is supplied to the track circuit through a low-voltage transformer whose leads are connected to the two rails at the exit end of the block. At the entrance end the track relay leads are connected in a similar manner and current-limiting resistances connected in series at either or both ends. When the signal current is shunted through a train axle in the block, the track relay drops and thereby initiates the resulting changes in the controlling circuits.

Signal Power Supply

The 100-cycle a-c energy for the signal system is supplied by duplicate motor

generator sets in the mole substation. One set provides ample power for the entire bridge railway, the other serving as a standby. The two sets are controlled by equipment which functions automatically to start and cut into service the standby in the event of any failure of the operating set.

Distribution of the 100-cycle energy is made at 2,300 volts with line transformers at frequent intervals stepping down the potential to 110 volts for service to the track transformers and code transmitters and to the rectifier transformers supplying the control circuits and their d-c relays.

The two-conductor 2,300-volt distribution cable is in duplicate, or looped, from end to end of the project. Oil switches on either side of each line transformer enable a transformer, or a section of cable between transformers, to be cut out without de-energizing other portions of the installation.

Interlocking Plants

In the Oakland yard, the interlocking plant includes the main tracks, the eight set-out tracks, the connections and switches between such tracks, switches for entering or leaving these tracks, and all signals governing routes through these interlocked switches. There are 36 interlocked switches and 62 color-light signals of the searchlight type in this plant. Main-track signals for the normal direction of traffic are one-unit or two-unit high signals. All others are single-unit dwarf signals. At the eastbound diver-

Table I

Code Interruptions Per Minute	Cab Signal Aspect	Nominal Authorized Speed (MPH)	Speed Above Which White Light Is Lighted (MPH)	Speed Above Which Warning Signal Is Sounding (MPH)	Speed at Which Emergency Brakes Are Automatically Applied (MPH)
180	Green	35	35	36	37
120	Yellow and green	25	25	26	27
75	Yellow	17	16½	17½	18⅛
None	Red	11	10¾	11¾	12¾

gence from joint track, the signal carries two white marker lights to indicate to the approaching train whether the switch is set for the Key System or the Interurban Electric connection. To give the approaching train the earliest possible warning, or assurance, as the case may be, the marker light is repeated at two preceding high signals.

In the San Francisco terminal loop, all switches and signals are interlocked. There are 36 switches and 40 dwarf signals.

Cab-signal blocks with code in the normal direction of traffic are carried continuously through both interlocking plants. The wayside signals are therefore primarily route signals but are arranged to operate in a manner consistent with track conditions. A yellow clear indicates a "no code" condition in the immediate block; that is, the motorman must expect that upon passing a yellow wayside signal, a "Red 11" cab signal will be received. With the normal control, a cleared signal will return to stop when the head of the train passes it; that is, the signal is a "stick" signal responsive to the occupancy of the immediate block. With a special control, however, the signal is made "non stick", will not be returned to stop by a passing train, and may be cleared even when the immediate block is occupied. Signals at entrances to cab-signal territory such as those leading from storage tracks to set-out tracks in the Oakland yard are known as "TC" signals. When a "TC" signal is cleared with the immediate block occupied, the aspect is a flashing yellow instead of steady yellow. With this aspect showing, the train comes to a stop before passing the signal. The choice of clear aspect, whether green, steady yellow, or flashing yellow, is automatic and entirely dependent on track conditions and not at all dependent on the choice between normal and special control.

Interlocking circuits are so arranged that a signal may not be cleared unless all switches in the route governed are properly positioned. Opposing or conflicting signals may not be clear at the same time. A switch may not be thrown while its block is occupied. No switch may be moved unless all signals governing through that switch are at stop. If a signal is thrown to stop in the face of an approaching train, switches in the route

Figure 1. Typical time-distance chart

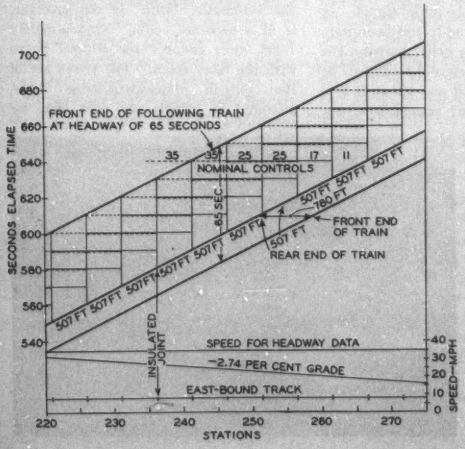
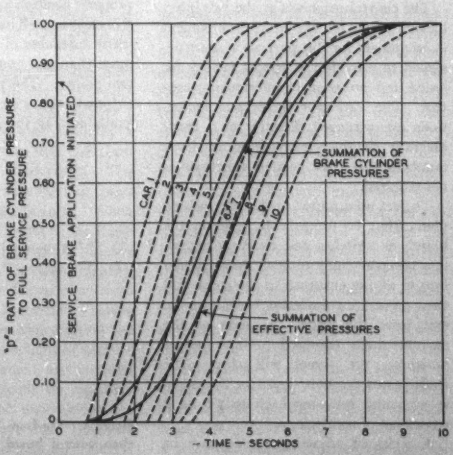


Figure 2. Initial rise in brake pressures



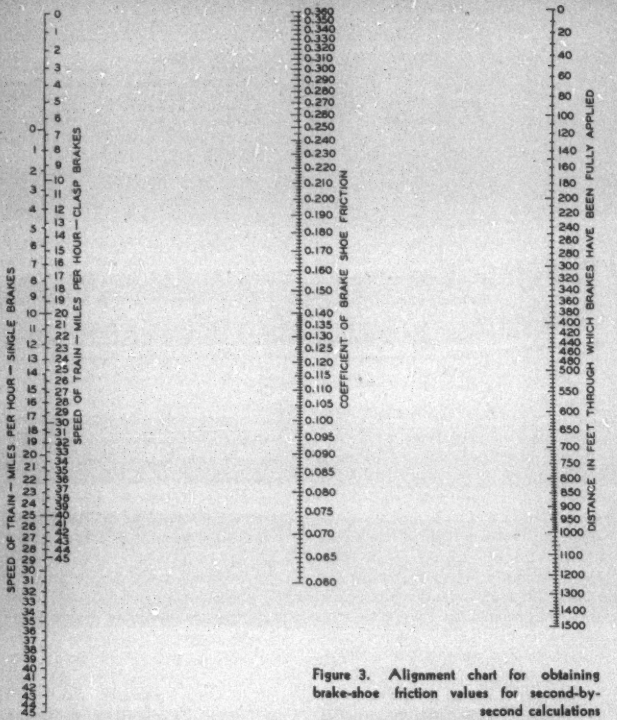

SPEED OF TRAIN — MILES PER HOUR — SINGLE BRAKES
SPEED OF TRAIN — MILES PER HOUR — CLASP BRAKES
COEFFICIENT OF BRAKE SHOE FRICTION
DISTANCE IN FEET THROUGH WHICH BRAKES HAVE BEEN FULLY APPLIED

Figure 3. Alignment chart for obtaining brake-shoe friction values for second-by-second calculations

will remain locked until a safe time interval has elapsed.

NX Control Machines

The control machines at the two interlocking plants are the latest development in equipment for this purpose and are designed to provide the utmost facility for speed and precision of interlocking control. The various controls and indications are arranged directly on a track diagram so that memorizing of lever numbers and their related functions is not required.

To "set up a route" in the interlocking plant, that is, properly to position the switch or switches and clear the signal, it is necessary only to push the initiation button at the entrance to the route and then push the completion button at the exit from the route. As soon as the switches have operated to their proper positions, the signal will clear. The train passes through, restoring the signal to stop and releasing each switch as it passes out of its block.

A series of adjoining routes may be operated as one, this being known as end-to-end operation. It is necessary only to press the initiation button of the first route and the exit button of the last route and all intervening switches will properly position and intermediate signals will clear as well as the initial signal. In many instances of end-to-end operation, more than one route exists between the two points. The preferred route will be automatically selected and set up if it is available. If for any reason it is not available, the machine will automatically select and set up the optional route. One end-to-end location in San Francisco has four possible routes which are automatically selected as available in their prescribed order of preference.

When initiating a route, the initiating button may be operated in either of two ways. It may be pushed or it may be rotated 90 degrees. If the route is set up by pushing the initiating button, any occupancy of the block immediately beyond the signal will return the signal to stop; therefore, the route may not be set up by this means if this immediate block is occupied. If the route is set up by rotating the initiating button, occupancy of the immediate block will not return the signal to stop and the route will remain set up for any following train or trains. A route that is set up may be cancelled by pulling the initiating button, if it had been pushed, or by rotating it back to the normal position, if it had been rotated.

On the San Francisco control board, in addition to the indications of signals, switches, and occupancy, a green light is provided on each of the six lines representing the six tracks in the train shed. When a train is ready to leave, the conductor presses a button on the platform. The corresponding green light on the board is lighted and remains lighted until the dwarf signal is cleared, authorizing the train to leave the shed.

The *NX* control machine contains the least possible quantity of the necessary control equipment; the push button and miniature switch contacts, the various indicators, and the thousand-odd terminal screws. The relays with their interconnections, the equipment which constitutes the automatic "brain" of the machine, is in a separate room. Approximately 1,000 wires connect the control board with the relay room. The relays are of the plug-in quick-detachable type, mounted on panels two feet wide by

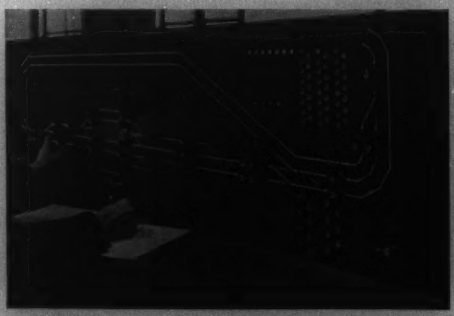


Figure 4. San Francisco control board

Figure 5. Air view showing the tracks of the San Francisco terminal loop

eight feet high. In San Francisco 22 of these panels, mounted back to back with a passageway between, contain 865 such relays. In Oakland the interlocking plant is naturally divided into eight groups of interlocked switches and signals. At each group remote from the tower is a "bungalow" containing the relays and the protective interlocking of circuits for that particular group. Only the necessary remote control and indication wires are carried from the bungalow to the control room. There are six such bungalows in the Oakland yard, the tower serving the purpose directly for two of the groups, and the number of relays is 1,328. In housings along the bridge between the two interlocking plants are 500 additional relays.

Train Describer Equipment

On each control machine at the right-hand end of the board is a special group of buttons and a group of lights which constitute the visible controls of the train describer equipment. These buttons and lights are lettered and numbered in accordance with the established identities of the various trains. When a train is given its outgoing route from the San Francisco plant, the operation is, as usual, the pushing of the entrance and the exit buttons. But in this case, instead of operating the regular exit button, the control-board operator is required to press one of this special group, thus setting up the identity of the outgoing train, as well as setting up and clearing the route. When the train accepts the signal the identity is transmitted to the Oakland control machine where it is eventually displayed in the group of lights on that board.

This system so functions that the nearest train approaching the plant is identified by the proper light in the number 1 group of 15 lights, the next train by a light in the second group and the third train by a light in the third group. The presence of additional approaching trains is shown by a single light for each. When a train passes the first signal of the interlocking plant, its identity light in number 1 bank is cancelled. The train identity shown in bank number 2 then jumps into number 1, that shown in number 3 moves into number 2, and the indication of the train shown by the single light of number 4 passes into bank number 3 and becomes identified. By this means the operator at the control machine may always see the identity of the next three trains to enter the plant and can plan accordingly. The train identities to the number of 15 are transmitted in either direction over a single pair of wires by means of variations in the polarities of four successive d-c impulses. The equipment includes 170 train describer relays at San Francisco and 102 at the Oakland control station.

Automatic Sorting of Trains

Although designed primarily for informing the tower of the identities of approaching trains, an additional and unique use is made of the train-describer system in controlling the entrance switch to the San Francisco interlocking. The identities of Interurban Electric trains are shown by numbers and those of the Key System by letters. Tracks 1, 2, and 3 in the terminal are assigned to the Interurban Electric Railway, and tracks 4, 5, and 6 to the Key System. At the entrance switch the preferred route for the Interurban Electric is therefore over the right-hand track and for the Key System over the left hand. In place of pushing the buttons to set up the proper route for each approaching train, the operator switches on "automatic sorting". The identification of each train is held by a bank of four relays. Number 1 of this bank is down for the numbered descriptions and up for the lettered descriptions. A front or a back contact of this number

1 relay is used to select the route and completion is automatic as soon as the switch is released by the passing train. The operator is thus enabled to forget the entrance switch entirely and all Interurban Electric trains are automatically routed over the right-hand track and all Key System trains over the left.

Train Describer Repeaters

The San Francisco control machine includes, in addition to the regular train-describer equipment, two groups of indication lights known as train-describer repeaters. These are mounted at the left end of the board and carry the descriptions after they are automatically cancelled at the entering switch until the trains pass the point from whence they are normally routed, each to its individual track in the station. Either of the two incoming tracks may be occupied by five short trains at one time and each repeater therefore is equipped with five groups of description lights. As the train passes through the entering switch its description is cancelled from the main describer, and enters the *N* repeater or the *R* repeater in accordance as the switch was in the normal or the reverse position.

Determination of Block Lengths

The extremely close headway between trains on the Bridge Railway, together with the heavy grades and frequent changes in grade, necessitated an unusually careful and elaborate investigation to determine the correct layout of signal blocks throughout the length of the project. It is necessary that these blocks and their controls not only permit the desired headway, but also provide safe braking distances at all points and under all conditions. The investigation included tests of the equipment actually operated over the bridge, as well as studies of existing data.

To verify the headway the signal blocks were laid out in the usual manner on time-distance charts. Figure 1 shows a typical portion of one of these charts where the grade is descending 2.74 per cent and the speed is constant at 35 miles per hour. The line designated as "front end of train" is first calculated and drawn. Where the speed is not constant a step-by-step method is used for the calculation. Scaling the train length of 780 feet to the left of this line, a second line is drawn parallel, representing the rear end of the same train at any instant. Still parallel to the first line, but scaling 65 seconds above it, a third line is drawn representing the front end of the following train.

A horizontal line drawn across these three lines will correctly represent the relative positions of the two trains at a given instant in time and, if the blocks are projected vertically from the track plan to this horizontal line, the arrangement of signal blocks between the two trains is shown. By drawing the hori-

Table II. Interurban Electric Railway Ten-Car Train, Test Condition, Braking From 30 Miles Per Hour, Level Grade

t	V	p	f	R_b = 16.4pf	$R_t = \frac{V+45}{450}$	$R = R_b + R_t$	V_n	D	SD	d	Sd	Sd_n
0	30.00											
1	29.83	0		0	0.17	0.17	29.92	43.9	43.9	0		
2	29.64	0.01	0.150	0.02	0.17	0.19	29.74	43.6	87.5	0.4	0.4	0.2
3	29.27	0.08	0.150	0.20	0.17	0.37	29.46	43.2	130.7	3.5	3.9	2.1
4	28.53	0.24	0.150	0.59	0.16	0.75	28.90	42.4	173.1	10.2	14.1	9.0
5	27.24	0.46	0.149	1.12	0.16	1.28	27.88	40.9	214.0	18.8	32.9	23.5
6	25.44	0.68	0.147	1.64	0.16	1.80	26.34	38.6	252.6	26.2	59.1	48.0
7	23.26	0.85	0.146	2.03	0.15	2.18	24.35	35.7	288.3	30.3	89.4	74.2
8	20.86	0.94	0.146	2.25	0.15	2.40	22.06	32.4	320.7	30.4	119.8	104.6
9	18.36	0.98	0.147	2.36	0.14	2.50	19.61	28.8	349.5	28.2	148.0	133.9
10	15.80	1.00	0.149	2.42	0.14	2.56	17.08	25.0	374.5	25.0	173.0	160.5
11	13.16		0.153	2.51	0.13	2.64	14.48	21.2	395.7	21.2	194.2	183.6
12	10.41		0.160	2.62	0.13	2.75	11.79	17.3	413.0	17.3	211.5	202.8
13	7.53		0.169	2.77	0.12	2.89	8.97	13.2	426.2	13.2	224.7	218.1
14	4.46		0.180	2.95	0.11	3.06	5.99	8.8	435.0	8.8	233.5	229.1
15	1.13		0.197	3.23	0.11	3.34	2.79	4.1	439.1	4.1	237.6	235.5
15.3	0		0.210	3.42	0.10	3.52	0.56	0.3	439.4	0.3	237.9	

NOTE: Two tests made under the above conditions resulted in measured distances of 429 feet and 431 feet, respectively.

Table III. Interurban Electric Railway Ten-Car Train, Braking From 37.74 Miles Per Hour, Minus Three Per Cent Grade

t	V	p	f	R_b = 16pf	$R_t = \frac{V+45}{450}$	$R = R_b + R_t - 0.61$	V_n	D	SD	d	Sd	Sd_n
0	37.74											
1	38.17	0		0	0.18	−0.43	37.95	55.6	55.6	0		
2	38.57	0.01	0.132	0.02	0.19	−0.40	38.37	56.2	111.8	0.6	0.6	0.3
3	38.82	0.08	0.130	0.17	0.19	−0.25	38.70	56.8	168.6	4.5	5.1	2.8
4	38.75	0.24	0.128	0.49	0.19	+0.07	38.79	56.9	225.5	13.6	18.7	11.9
5	38.26	0.46	0.124	0.91	0.19	+0.49	38.50	56.5	282.0	26.0	44.7	31.7
6	37.40	0.68	0.119	1.29	0.18	0.86	37.83	55.5	337.5	37.7	82.4	63.5
7	36.29	0.85	0.113	1.54	0.18	1.11	36.85	54.0	391.5	45.9	128.3	105.3
8	35.10	0.94	0.108	1.62	0.18	1.19	35.70	52.3	443.8	49.2	177.5	152.9
9	33.91	0.98	0.103	1.62	0.18	1.19	34.50	50.6	494.4	49.5	227.0	202.2
10	32.75	1.00	0.100	1.60	0.17	1.16	33.83	48.9	543.3	48.9	275.9	251.4
11	31.64		0.097	1.55	0.17	1.11	32.20	47.2	590.5	47.2	323.1	299.5
12	30.58		0.094	1.50	0.17	1.06	31.11	45.6	636.1	45.6	368.7	345.9
13	29.55		0.092	1.47	0.17	1.03	30.07	44.1	680.2	44.1	412.8	390.7
14	28.55		0.091	1.45	0.16	1.00	29.05	42.6	722.8	42.6	455.4	434.1
15	27.56		0.090	1.44	0.16	0.99	28.06	41.2	764.0	41.2	496.6	476.0
16	26.59		0.089	1.42	0.16	0.97	27.08	39.7	803.7	39.7	536.3	516.4
17	25.63		0.088	1.41	0.16	0.96	26.11	38.3	842.0	38.3	574.6	555.4
18	24.69		0.087	1.39	0.16	0.94	25.16	36.9	878.9	36.9	611.5	593.0
19	23.76		0.087	1.39	0.15	0.93	24.23	35.5	914.4	35.5	647.0	629.2
20	22.83		0.087	1.39	0.15	0.93	23.30	34.2	948.6	34.2	681.2	664.1
21	21.90		0.087	1.39	0.15	0.93	22.37	32.8	981.4	32.8	714.0	697.6
22	20.97		0.087	1.39	0.15	0.93	21.44	31.5	1012.9	31.5	745.5	729.7
23	20.04		0.087	1.39	0.15	0.93	20.50	30.1	1043.0	30.1	775.6	760.5
24	19.10		0.088	1.41	0.14	0.94	19.57	28.7	1071.7	28.7	804.3	790.0
25	18.16		0.088	1.41	0.14	0.94	18.63	27.3	1099.0	27.3	831.6	818.0
26	17.21		0.089	1.42	0.14	0.95	17.69	25.9	1124.9	25.9	857.5	844.6
27	16.26		0.089	1.42	0.14	0.95	16.74	24.6	1149.5	24.6	882.1	869.8
28	15.30		0.090	1.44	0.13	0.96	15.78	23.1	1172.6	23.1	905.2	893.7
29	14.31		0.092	1.47	0.13	0.99	14.80	21.7	1194.3	21.7	926.9	916.0
30	13.30		0.093	1.49	0.13	1.01	13.80	20.2	1214.5	20.2	947.1	937.0
31	12.28		0.094	1.50	0.13	1.02	12.79	18.8	1233.3	18.8	965.9	956.5
32	11.22		0.096	1.54	0.13	1.06	11.75	17.2	1250.5	17.2	983.1	974.5
33	10.14		0.098	1.57	0.12	1.08	10.68	15.7	1266.2	15.7	998.8	991.0
34	9.03		0.100	1.60	0.12	1.11	9.59	14.1	1280.3	14.1	1012.9	1005.8
35	7.89		0.102	1.63	0.12	1.14	8.46	12.4	1292.7	12.4	1025.3	1019.1
36	6.70		0.105	1.68	0.12	1.19	7.30	10.7	1303.4	10.7	1036.0	1030.6
37	5.47		0.108	1.73	0.11	1.23	6.09	8.9	1312.3	8.9	1044.9	1040.4
38	4.18		0.112	1.79	0.11	1.29	4.83	7.1	1319.4	7.1	1052.0	1048.4
39	2.82		0.116	1.86	0.11	1.36	3.50	5.1	1324.5	5.1	1057.1	1054.5
40	1.39		0.121	1.94	0.10	1.43	2.10	3.1	1327.6	3.1	1060.2	1058.6
40.9	0		0.127	2.03	0.10	1.52	0.70	0.9	1328.5	0.9		1060.6

zontal lines at such points that the rear end of the train is shown as just having passed an insulated joint, the restrictive distance behind the train is at its minimum length. There must then be one full unrestricted block ahead of the following train, so that it may proceed through that block on a clear signal during the time that will elapse before the rear end of the leading train will pass beyond another insulated joint and thereby step the restrictive conditions another block forward.

In checking braking distances, the leading train is considered stationary with its rear axle immediately ahead of an insulated joint. When closing up on a standing train a restrictive block must be encountered at such a distance behind that insulated joint as will enable the motorman to bring the train from its maximum possible speed to a safe stop. This required distance includes five items as follows:

1. Travel during time required for operation of signal equipment (2 1/2 seconds).

2. Travel during allowed time for motorman's reaction (2 1/2 seconds).

3. Travel from initiation of service-brake application until train is stopped.

4. Safety factor for defective brakes or slippery rails, 25 per cent of item 3.

5. Overhang of two trains beyond end axles (20 feet).

Items 1 and 2 are taken together as the travel at the maximum possible speed for five seconds. The maximum possible speed under any control is the speed which would result in an automatic brake application, plus two per cent error for governor maladjustment. For the maximum fully loaded ten-car Interurban Electric train on level track the items are as follows:

Items 1 and 2, $\frac{5\times37.74\times5280}{3600}$ =	277 feet
Item 3, level grade, from 37.74 miles per hour	1,329 feet
Item 4, 25 per cent of item 3	332 feet
Item 5	20 feet
Total	1,958 feet

It will be seen that only items 3 and 4 will vary with the grade and only item 3 requires extensive investigation.

The chief factors influencing the effect of brakes upon a railway train may be listed as follows:

1. The nominal pressure of the brake shoes against the wheels when the brake cylinders are at their full operating pressure.

2. The efficiency of the brake rigging in transmitting this pressure.

3. The coefficient of friction which enables this pressure to effect a tangential force on the wheel rims.

4. The variation in effective brake pressure during the period of initial application before all brake cylinders are at their full operating pressures.

5. The weight of the train, including its load.

6. The inertia effects of rotating parts, such as wheels and axles and parts such as motor armatures which are geared to the wheels and axles.

7. The train resistance or those components of mechanical friction which oppose the motion of the train at a constant speed on tangent level track in still air.

8. The grade over which the train is moving.

9. Curvature of the track over which the train is moving.

These factors as they entered into our own particular problem were as follows:

1. Total nominal brake-shoe pressure (pounds):

Interurban Electric ten-car train, six motor cars, four trailers, with equalization at 50 pounds	942,000
With equalization at 60 pounds	1,130,400
Key System seven-unit train with single brakes	1,181,900
With clasp brakes	1,057,700

2. Brake rigging efficiency, taken in all cases as 85 per cent.

3. The most extensive records of the effect of railway brakes are of the very elaborate and lengthy series of experiments made by Captain Douglas Galton in 1878 on the Brighton Railway in England. As is true of most braking studies made since that date for speeds under 60 miles per hour, Galton's observations have been the basis for our studies and, together with the tests made with Key System and Interurban Electric equipment, comprise the data from which our friction formulas have been derived.

For use in our braking calculations the coefficient of brake-shoe friction is taken as continuously varying with the speed and with the distance through which the brakes have been applied. For clasp brakes our formula is

$$f_1=\frac{36}{100+3V}$$

in which V is the speed in miles per hour. This gives a curve which approaches the maximum extremes observed by Galton without exceeding his maximum observation for any speed. Galton's tests were made with clasp brakes. For single brakes we have used values somewhat less than the mean of his observations, having found that such values agreed with our tests. The formula used for single brakes is

$$f_1=\frac{9}{30+V}$$

The reduction factor for distance, F, is taken as equal to the ratio,

$$\frac{10{,}000+5d}{10{,}000+24d}$$

in which d is the distance in feet through which the brakes have been fully applied. The final coefficient is then given by the formula,

$$f=Ff_1$$

and the nomograph, figure 3, is designed for conveniently obtaining the resulting values.

The coefficient of friction at low partial pressures is assumed to vary as the square root of the pressure and this variation is included in the curve of summation of effective pressures in figure 2.

4. When a service-brake application is made, the reduction in air pressure, followed by the operation of the triple valve, is first effective in the head car and then successively in the following cars of the train. Further, the normal pressure of the brake shoes on the wheels is not applied instantly, but rises gradually from zero to full pressure. For use in making braking calculations, standing tests were made of

Table IV. Interurban Electric Railway Ten-Car Train, Braking From 18.87 Miles Per Hour, Minus Three Per Cent Grade

t	V	p	f	R_b = 16 pf	R_t = V+45 / 450	R = R_b+R_t −61	V_a	D	SD	d	Sd	Sd_a
0	18.87											
1	19.34	0		0	0.14	−0.47	19.10	28.0	28.0			
2	19.78	0.01	0.182	0.03	0.14	−0.44	19.56	28.7	56.7	0.3	0.3	0.2
3	20.02	0.08	0.180	0.23	0.14	−0.24	19.90	29.2	85.9	2.3	2.6	1.5
4	19.81	0.24	0.178	0.68	0.14	+0.21	19.92	29.2	115.1	7.0	9.6	6.1
5	18.98	0.46	0.177	1.30	0.14	+0.83	19.40	28.5	143.6	13.1	22.7	16.1
6	17.54	0.68	0.176	1.91	0.14	1.44	18.26	26.8	170.4	18.2	40.9	31.8
7	15.61	0.85	0.177	2.40	0.14	1.93	16.58	24.3	194.7	20.7	61.6	51.2
8	13.42	0.94	0.178	2.67	0.13	2.19	14.52	21.3	216.0	20.0	81.6	71.6
9	11.03	0.98	0.183	2.87	0.13	2.39	12.23	18.0	234.0	17.6	99.2	90.4
10	8.48	1.00	0.190	3.04	0.12	2.55	9.76	14.3	248.3	14.3	113.5	106.3
11	5.77		0.200	3.20	0.12	2.71	7.13	10.4	258.7	10.4	123.9	118.7
12	2.87		0.213	3.40	0.11	2.90	4.32	6.3	265.0	6.3	130.2	127.0
12.9	0		0.232	3.71	0.10	3.20	1.43	1.9	266.9	1.9		131.0

Five seconds at 18.87 miles per hour =	138 feet
Calculated braking distance =	267
25 per cent of braking distance =	67
Overhang =	20
Minimum length of one block	492 feet
Actual block on minus 3 per cent grade	507 feet

the rate of rise in brake cylinder pressures of an Interurban Electric ten-car train. These pressure rises were charted and, after consideration was given to the effect of reduced pressures on brake rigging efficiency and on coefficients of friction, a curve of summation of effective pressures was added to the chart (figure 2). Similar data were obtained for a Key System train of seven articulated units. The effective pressure factors for the first ten seconds of a service brake application as used in our calculations are as follows:

Second	Factor for Interurban Electric Railway	Factor for Key System
1	0.0	0.0
2	0.01	0.0
3	0.08	0.08
4	0.24	0.43
5	0.46	0.78
6	0.68	0.97
7	0.85	1.00
8	0.94	1.00
9	0.98	1.00
10	1.00	1.00

5. The weights in pounds of the various trains involved were as follows:

Interurban Electric ten-car train	970,000
Maximum passenger load	250,000
Total weight	1,220,000
Key System train with clasp brakes	952,000
Maximum passenger load	296,000
Total weight	1,248,000
Key System train with single brakes	910,000
Maximum passenger load	296,000
Total weight	1,206,000

6. We have found that the inertia of the rotating parts of either of our maximum trains is equivalent to the addition of approximately 100,000 pounds to the weight. This is the weight equivalent of the rotating parts and, when this is added to the total weight of the train, the sum is the total weight-equivalent of the train.

7. Train-resistance data were obtained by drift tests on level track. From these tests formulas were derived as follows:

For Interurban Electric, $R_t = \frac{V+45}{450}$

For Key System, $R_t = \frac{V+40}{1{,}000}$

in which R_t is the retardation in miles per hour per second caused by train resistance and V is the speed in miles per hour. The low train resistance of Key System equipment is a result of the installation of roller-bearing journals in all trucks.

8. Grades on the bridge railway vary from three per cent descending to four per cent ascending and lengths of blocks vary accordingly.

9. Resistance caused by track curvature was a factor in the calculation of our speed-time-distance charts, but its effect on braking was not of great importance and will not be discussed here.

To calculate the distance traveled from the initiation of a service brake application until the train is stopped, a second-by-second method is used. The retardation of the speed of a train, caused by the application of the brakes during a period of one second, is obtained by the formula

$$R_b = G \cdot r \cdot e \cdot p \cdot f$$

in which

G is the constant of acceleration caused by gravity in miles per hour per second, taken as 21.93

r is the nominal braking ratio, the ratio of the total nominal brake shoe pressures to the total weight-equivalent of the train

For the Interurban Electric fully-loaded ten-car train

$$r = \frac{1{,}130{,}400}{1{,}220{,}000+100{,}000} = 0.856$$

For the ten-car light train of the preliminary tests

$$r = \frac{942{,}000}{970{,}000+100{,}000} = 0.880$$

For the Key System fully loaded train with clasp brakes

$$r = \frac{1{,}057{,}700}{1{,}248{,}000+100{,}000} = 0.785$$

and with single brakes

$$r = \frac{1{,}181{,}900}{1{,}206{,}000+100{,}000} = 0.905$$

For the Key System light train with clasp brakes

$$r = \frac{1{,}057{,}700}{952{,}000+100{,}000} = 1.006$$

with single brakes

$$r = \frac{1{,}181{,}900}{910{,}000+100{,}000} = 1.170$$

e is the brake rigging efficiency taken as 0.85

p is the ratio of total effective pressure to total full pressure

f is the coefficient of friction for the second involved and is obtained by means of the nomograph, figure 3, after the average speed for that second and the average distance through which the brakes have been applied have been estimated

In the formula for R_b, G, r, and e are constant for a given train condition. For the fully loaded Interurban Electric train

$$G \cdot r \cdot e = 21.93 \times 0.856 \times 0.85 = 16.0$$

and the formula for this train may be simplified to

$$R_b = 16 \cdot p \cdot f$$

The total retardation per second is equal to the retardation caused by braking, plus that caused by train resistance, plus that caused by grade, or

$$R = R_b + R_t + R_g$$

R_g is positive or negative in accordance as the grade is ascending or descending. The formula is

$$R_g = s \cdot G \cdot \frac{W}{W_e}$$

in which s is the grade, G is the gravity acceleration constant, W is the total weight, and W_e the total weight-equivalent of the train. For the loaded ten-car train on a three-per-cent descending grade

$$R_g = -0.03 \times 21.93 \times \frac{1{,}220{,}000}{1{,}320{,}000} = -0.61$$

miles per hour per second.

In the typical calculations shown, symbols which have not been fully discussed are as follows:

V, speed, miles per hour, at the end of each second

V_a, average speed during the second

D, distance in feet traveled during the second

SD, total distance traveled since brake handle was placed in service position

d, equivalent distance $(D \cdot p)$ brakes were fully applied during the second

Sd, total equivalent distance brakes have been fully applied to end of second

Sd_a, total equivalent distance brakes have been fully applied to middle of second

After the final braking distance for a given speed and grade has been calculated and the required over-all length of the restrictive blocks obtained, the minimum length of a single block is found. On descending grades we have four restrictive blocks in the rear of the occupied block and three restrictive blocks where the grade is level or ascending. Our standard rail length is 39 feet and where practicable the block length is a multiple of 39 feet or of one-half of 39 feet.

In order to check the length of two blocks for braking from the 25 control, and of one block for the 17 control, calculations must also be made for braking from 27.54 and 18.87 miles per hour. For the project under discussion, braking distances were calculated for level grade, one, two, and three per cent descending, and one, two, and three per cent ascending grades.

In the typical tabulations shown, all calculations were made with slide rule. The formulas given herein for various functions of speed are not considered applicable to train speeds greater than 50 miles per hour.

A New Technique for Lead Cable Sheathing

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Synopsis: A new technique used in the production of lead sheaths for electric power cables is introduced. The various phases of the problem and the difficulties encountered heretofore are described. It has been found that it is necessary to consider the problem both as a mechanical and a chemical one. A method is described in which both factors are used. This consists in pretreating lead as received with a sodium-lead alloy to remove all deleterious impurities and the use of a special standpipe procedure for filling the lead-press extrusion cylinder to obtain a complete union of successive charges, resulting in sound lead sheaths throughout the entire cable length. Test data show that the physical and corrosion properties of lead are not adversely affected by the sodium treatment.

THE HISTORY of the cable-making art shows some very interesting facts. Twenty years, and more, ago, while the use of electric power in the United States was increasing rapidly and the electric power utilities were trying to meet the demand for the transmission of power with the installation of cables operating at higher voltage than heretofore used, they seemed to be held back because of the poor operating record of the cables furnished. A study of the situation showed it to be due to the nature of materials (paper and oil) used for insulation and the lack of proper drying, degasifying, and impregnation methods. In time, this situation was overcome and the rate of cable failures due to defective insulation decreased. However, with the improvement in the technique of insulation manufacture a new problem came to plague both the manufacturer and the cable user.

Paper 39-140, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939. Manuscript submitted March 22, 1939; made available for preprinting May 15, 1939; released for final publication September 6, 1939.

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This accomplishment has taken several years to bring to a successful conclusion and required the combined efforts of our production and technical staffs. Among the latter who co-operated in this development were H. L. Beede, technical manager; F. H. Gooding, research engineer; and B. Critchley, assistant chemist.

1. For all numbered references, see list at end of paper.

About 1931 an increase in cable failures due to the lead sheath was noted and this seemed to continue for several years, until today it is found that the major portion of inherent cable failures as reported by the Association of Edison Illuminating Companies and the Edison Electric Institute are due to defects in the lead sheath.

Recognition of the lead sheath as a source of trouble led to an intense investigation of the physical properties of lead as well as manufacturing methods of making lead pipe. As a result, we find some valuable papers written by Moore and his associates, of the University of Illinois,[1] McKeown,[2] and Waterhouse.[3]

The research staffs of the public utilities, such as Commonwealth Edison Company, Philadelphia Electric Company, and Detroit Edison Company, have reported at technical meetings from time to time on their studies. At the same time the cable manufacturers were spending large sums of money on the improvement of manufacturing methods as well as researches on the physical properties of lead as used in cable sheathing. Some of these have been published through technical organizations, such as Bassett and Snyder,[4] Phillips,[5] Dunsheath,[6] and others privately, such as Sherman.[7] All authors were interested in the physical properties of lead and have contributed to the knowledge of the action of lead under physical stress, yet it cannot be said that they advanced the solution of the lead-sheath problem as rapidly as desired. The influence of internal stresses on the expansion of the sheaths was widely studied but we still had the lead-sheath problem as distinct from lead in strip form.

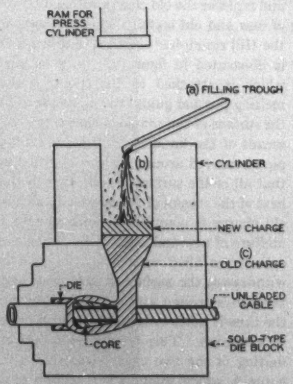

Figure 1. Trough filling of cylinder

The cable manufacturers gave serious study to the improvement in manufacture of lead sheaths. Various methods, mostly of a mechanical nature and referred to as "improved foundry practice," were tried out. Under this slogan we find the vacuum press,[8] in which the lead-press cylinder is filled with molten metal under conditions in which most of the air is eliminated; hydrogen flame,[9] where the metal is poured in the presence of burning hydrogen which reacts with the oxygen in the vicinity of the molten lead and prevents further surface oxidation of the molten metal; electric arc and oxy-acetylene flame which melt the oxidized surface of the residual charge so as to assist in the union of the two charges; high density inert gas,[10] which is used to maintain a nonoxidizing gas blanket over the molten lead in the melting pot and to replace the normal atmosphere or air as far as possible during the time of pouring; continuous extrusion machines,[11] which have been developed in Europe in which the lead is never in contact with air. Mechanical difficulties have been encountered which have delayed the extensive use of this type of machine and at the present time it cannot be considered as a commercial lead press free of shortcomings. Our company studied the claims made for each of the above lead-press processes hoping to find a solution to the problem of elimination of flow lines and laminations in lead sheaths. Some of them appeared to have merit, others were fair, and some of no value. We were able to try all but the vacuum press and the continuous extrusion machine sufficiently long to make us feel that from our viewpoint they were not able to accomplish what we were seeking, namely, a continuously uniform cable sheath no matter how many cylinder charges were required which did not have critical regions, charge welds, or laminations.

A careful study of lead-pipe manufacture indicated that there are two distinct problems. One of these problems pertains to the method of filling the lead-press cylinder with new molten lead and the other deals with the chemical stability of the lead itself. These two problems are closely related and by solving both we have a means to obtain the desired end.

Figure 2 (left). Non-union of charges

Figure 3. Cable sheath resulting from trough filling

Let us discuss first what happens when the cylinder of a lead press is filled. Figure 1 is a sketch showing the pouring of molten lead from the melting pot into the cylinder. The lead flows along a trough (*a*) to the cylinder and then splashes itself into a broken stream (*b*) as it fills the cylinder. A considerable amount of air becomes occluded and further oxidation of the hot lead takes place so that the cylinder of lead contains gas and lead oxides. Moreover, the previous charge (*c*) is solid and has a surface temperature of about 250 degrees Fahrenheit compared with that of 700 degrees Fahrenheit for the new lead. The incoming molten lead is chilled as it strikes the surface of the old lead, resulting in the condition shown in figure 2. The two charges are easily separated yet they are forced down through the lead block, around the core to form a lead sheath. Such a pipe is not a sound lead sheath, but contains flow lines, laminations, and poor welds, particularly in the so-called critical regions where the lead at the union between the two charges is extruded. If rings are cut along the pipe and etched, we find crystal structures, such as shown in figure 3, which clearly indicate flow lines full of inclusions. Such a pipe is none too strong and in time under stress will produce leaks. The electric arc, oxyacetylene flame, and continuous extrusion machines attempt to correct the nonuniting of charges. This is difficult to accomplish by the first two methods as the molten surface of the residual charge has already started to chill before the new lead reaches it. The continuous extrusion machine may have great promise but it is still in the development stage and many problems pertaining to the control of temperature in its various parts and the overcoming of severe oxidation within it if allowed to cool have yet to be solved.

Recognizing the importance of getting successive charges of lead to unite, we adopted the method developed by our associate company in England, Callender's Cable and Construction Company, Ltd., of bottom filling in which the molten lead is directed by means of a pipe to the surface of the previous charge. This eliminates the splashing that usually takes place, and therefore, the entrapping of air, at the same time causes the new hot lead to melt the surface of the previous charge while the cylinder is being filled and replaces the old charge with a mixture of new and old metal. This is known as the Hill standpipe[14] method of filling and is illustrated in figure 4. (*a*) is a pipe which is attached to the spout of the melting pot and guides the molten lead to the surface of the previous charge (*b*); by means of the handles (*c*) the end of the pipe is moved around by the operator so that all of the surface is subjected to the heat of the stream of the new lead and the old charge is completely replaced with a mixture of new and old metal. When the cylinder is filled with lead, the pipe is withdrawn, the surface is skimmed, and the ram is pressed against the lead during the time it takes to solidify the lead prior to extrusion. This results in a perfect uniting of the two charges, as shown in figure 5, which shows a half section of a slug removed from the press and a perfect joining of the lead. The remains of the old charge can be identified by the small-size grain structure resulting from the previous pressure cycles. Slabs may be cut from the other half and bent into a U shape without showing any splitting where the charges unite.

Although a better lead sheath than formerly was obtained, it was noted that there were oxides and other deleterious impurities still present in the lead as inclusions. Since inclusions are known to cause defects in cable sheaths, it is obvious that their complete elimination is desirable if it is intended to improve the quality of the lead pipe. We therefore studied various ways which have been pro-

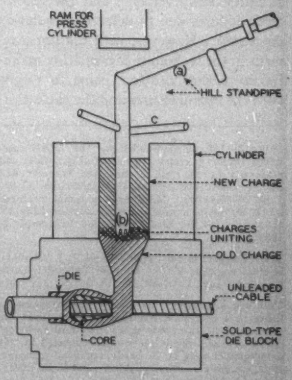

Figure 4. Hill standpipe method of filling cylinder

posed to remove entrapped impurities in lead. While the vacuum press will remove free gases during the filling of the cylinder and thus eliminate oxidation in this respect, it cannot reduce entangled oxides, decompose sulfides, or eliminate other deleterious impurities already present in the lead in the melting pot; such impurities are to some extent soluble in and occluded by the molten metal.[11–13] The impurities segregate themselves between the lead crystals and thus weakness and corrosion along crystal boundaries results. When cooling is rapid as in the case of the molten metal while being transferred from the melting pot into the lead-press cylinder, the impurities have no time to separate, and are therefore interspersed throughout the mass and not merely at the so-called critical region. Furthermore, the deleterious impurities are not only detrimental in themselves, but they also bring about a condition whereby small amounts of oxidation products act as catalysts and thus there is a possible progressive acceleration of oxidation and decomposition taking place in the melting pot.

When commercial lead is melted, the dross removed, and then remelted, the tendency for dross formation in the molten state will be as before. D. M. Smith[13] has shown that on melting lead in a vacuum of the order of 0.025–0.015 millimeter mercury pressure, dross appeared on the surface and increased in quantity on agitation of the molten metal. Two or three purifications under vacuum were necessary to practically prevent continued dross formation.

As stated above, the use of a hydrogen flame to reduce the oxides as the lead is poured into the cylinder is not completely effective. The flame contacts only the surface of the stream of molten metal, and, therefore, merely prevents further oxidation without helping the situation. This method alone does not bring about complete union of charges.

While the surface of the residual charge can be melted by the electric arc or oxy-acetylene flame, the oxides originally present will only be disturbed but not removed. When pouring the new charge of lead at the usual pouring temperature, which is around 750–775 degrees Fahrenheit, there will not be sufficient fluidity or residual heat to allow those oxides, sulphides, and other deleterious impurities which are insoluble in molten lead to rise to the surface and be skimmed off.

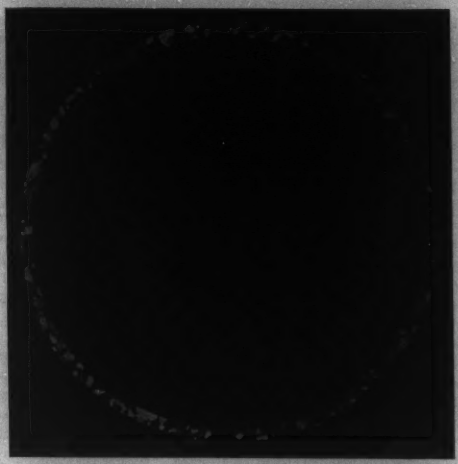

Figure 6. Cable sheath resulting from Hill standpipe filling

The use of inert or reducing gases in the lead-press cylinder is ineffective as the release of the gas under pressure has a cooling effect on the molten metal entering the cylinder. The lowered temperature and marked sluggishness of the molten lead prevents proper welding between charges. Moreover, the oxides in solution which are always present in molten metal are unaffected. Besides, foaming of the molten metal and occlusion of some of the gas takes place, thus bringing about blistering, gas pockets, and sponginess in the extruded sheath. Even when inert gas is used with a positive pressure over the melting pot, dross with an appreciable amount of red lead accumulates. The other methods referred to all suffer from similar difficulties.

Apart from the many efforts to bring about some sort of stability to the molten lead as it enters the lead-press cylinder, various means have been employed to reduce as far as possible surface oxidation of the molten lead in the melting pot. Such ingredients as burnt clay, sand, powdered mica, charcoal, graphite, fluxes, various salts, and mechanical contrivances have been used. Stabilization of lead has also been attempted under different circumstances, using chlorine, phosphorus, boron trichloride, titanium tetrachloride, vanadium trioxide, lithium, and a host of other reducing and deoxidizing substances. In all such cases the reagents failed to bring about the desired results.

Figure 5. Complete union of charges

Recognizing the shortcomings of all the

methods in use for the stabilization of lead, we proceeded to experiment with various deoxidizing and reacting substances so that the treated metal may not only be free from occluded oxygen and

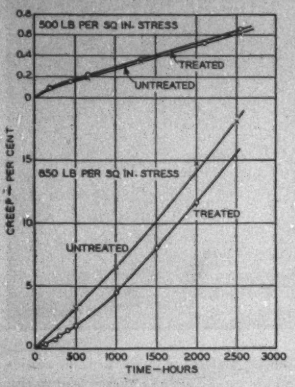

Figure 7. Creep tests on lead strips cut from cable sheathing

Temperature 15 degrees centigrade

other gases, but also free of entangled oxides, sulphides, and other deleterious impurities; moreover, that after the elimination of all such impurities, the treated metal should be immune from further oxidation and contamination in process of extrusion.

After conducting a research extending over a period of several years, it was found that the desired end could be accomplished by the chemical stabilization of lead and its alloys. The active reagent that brings about this stabilization is metallic sodium, a member of the alkali metals in the periodic group, preceded by lithium and followed by potassium. Sodium, when used within critical limits and under prescribed conditions, stabilizes lead without at the same time changing the basic physical characteristics or affecting adversely the corrosion-resistant properties of the treated metal. It can be obtained as a relatively stable alloy of lead and is commercially available at a reasonable price. Since metallic sodium is quite reactive and dangerous to handle under atmospheric conditions, apart from the fact that uniformity of treatment is difficult, it is necessary to alloy it under controlled conditions with lead and this alloy is then introduced into the lead to be stabilized.

The amount of master alloy to use depends upon the kind of lead to be treated and the impurities present in the metal as received from the refinery. For example, as little as 0.005 per cent of metallic sodium cleanses, and as a result imparts a silvery color to electrolytic lead. This type of lead, which is known to dross more than any other commercial lead on the market, may then be heated at elevated temperatures for long periods of time in an open pot without contamination.

The critical amount of sodium used in this treatment of lead ranges from 0.005 per cent to 0.05 per cent by weight of the amount of lead being treated. Upon the addition of the sodium-lead alloy to the molten lead, the alloy is broken down into its component parts at a temperature of 850–900 degrees Fahrenheit. The sodium thus released combines with any free or dissolved oxygen, reduces the various oxides, and decomposes as well as throws out of solution such deleterious compounds as sulphides which are usually present in commercial lead. The deleterious impurities thus released float to the top of the molten mass of metal from which they are readily skimmed off.

This method of treatment results in a trace of sodium of the order of 0.001 per cent remaining in the lead. This small amount of residual sodium has a stabilizing effect upon the treated lead in that the latter may be allowed to solidify, then remelted without the necessity of again treating with sodium-lead alloy. The remelted lead not only does not dross, but retains the same silvery appearance and physical characteristics as the lead resulting from the first treatment.

It is possible to keep the treated lead, due to its stability, at temperatures as high as 850–900 degrees Fahrenheit in the melting pot for long periods of time without fear of dross formation and without affecting the physical characteristics of the extruded metal. This treatment overcomes the natural sluggishness of lead and its alloys at any given temperature below red heat. The increase in fluidity of the molten metal together with the higher pouring temperature is a distinct advantage, as it not only helps to float to the surface any foreign matter which might find its way into the cylinder, but also facilitates the fusion and welding of the old with the new charge.

For lead alloys, the lead is first pretreated and then the alloying metal, as

Figure 8. Increase in pipe volume due to steady internal pressure of 62 pounds per square inch (500 pounds per square inch hoop stress)

Temperature 25 degrees centigrade

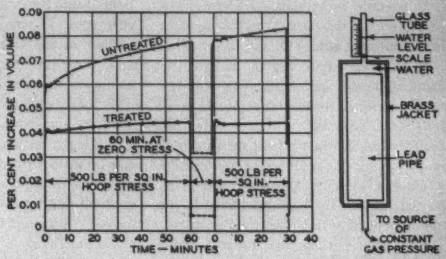

Table I. Physical Tests

	Tensile Strength* (Pounds per Square Inch)	Elongation (Per Cent in One Inch)	Rockwell Hardness Number **	90-Deg Bends Original IPCEA† Machine
Electrolytic				
Untreated	1,980	75	62	88
Treated	2,010	83–87	65–67	72–84
St. Joseph (0.06 per cent copper)				
Untreated	2,350	66	72.5	50–66
Treated	2,280	78–78.5	72.5	58–66
Electrolytic and 0.01 per cent lithium				
Untreated	2,680	58	92.6	27
Treated	2,890	65	88	27
St. Joseph and 2 per cent tin				
Untreated	3,140	62.5	85.2	24
Treated	2,980	72	75	23

* Speed of machine one inch per minute.

** Model *R H*, one-half-inch ball penetrator, 30-kilogram load. Anvil $^1/_4$-inch flat spot. Time factor 30 seconds.

† Insulated Power Cable Engineers Association.

Table II. Bend Tests

Type of Lead	Time of Test	Single 90-Deg Bends, IPCEA Machine: Average	Maximum	Minimum
Electrolytic	Immediately	50	72	40
	One week later	78	100	56
	Two years later	92	106	78
St. Joseph	Immediately	52	78	42
	One week later	76	90	60
	Two years later	89	100	78

such, or in the form of a master alloy, is added. Here also, it is possible to maintain a high temperature in the melting pot. The extruded alloy sheath shows uniform dispersion of the alloying metal and is free from inclusions or laminations.

Although our method of treatment consists in taking a mixture of lead and sodium, which we call the master alloy, and dissolving it in the molten lead to be treated, we do not get as a result an alloy of lead in the final product.

To determine what influence the treatment has on the physical and corrosion-resistance properties of lead, experiments were conducted on both types for comparison. Table I shows typical physical properties for several types of lead and lead alloys.

Taking bend tests[8] as an indication of aging, table II shows the change in two kinds of treated lead immediately, one week, and two years after extrusion. It is to be noted that recrystallization or self-annealing has taken place and the range between maximum and minimum bends are closer after two years than when first tested, which is typical of commercial lead.

Creep tests on treated and untreated lead strips, and expansion tests on pipe have indicated that the treated lead is somewhat superior in resisting distortion due to stress even when the standpipe method of filling the cylinder is used in both instances.

Figure 7 shows the results of creep tests made at 500 and at 850 pounds per square inch. At 500 pounds per square inch there is practically no difference, but at 850 pounds per square inch the untreated lead stretches faster than the treated metal. This might be expected because of the improved crystal bond that is characteristic of the treated lead, and which reduces that part of the flow which is associated with the crystal boundaries.

Expansion tests were made on samples of lead pipe, sealed at the ends, and subjected to internal pressure. The increase in volume of the pipe was measured by the water displacement method shown at the top of figure 8. The initial creep and creep rate and the elastic recovery when stress is removed are shown for a 62-pound-per-square-inch (500 pounds per square inch hoop stress) pressure cycle, lasting one hour. This is followed by a one-hour zero-pressure period and a further one-half hour stress period. The initial creep and creep rate are greater for the untreated lead. The recrystallization during the one-hour rest period was negligible in both cases.

Stress-strain curves, made on similar samples of lead pipe, exhibited the same tendencies, see figure 9. The pressure was raised by 10-pound steps, and the increase in volume noted at each step. At 50 pounds per square inch the untreated pipe began to expand rapidly, and had reached the short-time yield point. The treated pipe went to 70 pounds per square inch before this point was reached.

The combination of the Hill standpipe method of filling the lead cylinder and the use of treated lead has resulted in an improved quality of lead sheath. Several years ago, while making the study of the various methods proposed for obtaining better sheaths, it was realized that to appreciate the full value of any improvement in lead-press technique it was necessary to test full-charge lengths of pipe, extruded under normal production conditions, instead of short specimens. Therefore, a time-pressure test was set up by taking full-charge lengths having about 2.80 inches outside diameter and 0.141 inch wall. Both ends are sealed and an internal pressure of 90 pounds per square inch of air (805 pounds per square inch circumferential stress) is applied for ten days and then the pressure increased 10 pounds per square inch internal pressure every five days until rupture occurs. The early tests with former process resulted in many of the samples failing on the first step and usually on a charge weld, or close to a die weld, where the tongues of the flow lines were very pronounced, resulting in blunt fractures. With the new technique the pressure reached on the average the 130 pounds per square inch step internal pressure (1,160 pounds per square inch circumferential stress) before rupturing which normally occurs at the thinnest part of the sheath and with a clean knife-edge fracture. Figures 10 and 11 show the rupture of lead pipes made by the old and new methods. Monthly checks are made on full-charge lengths from regular factory production runs and

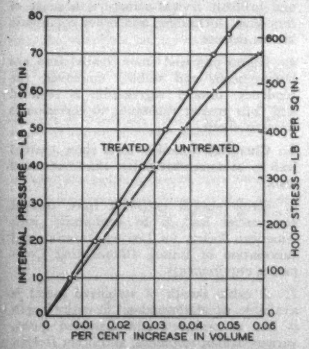

Figure 9. Increase in pipe volume due to rising internal pressure

Pressure increased at ten pounds per square inch per ten seconds

Temperature 25 degrees centigrade

Figure 10. Pressure-test rupture of pipe made by old method

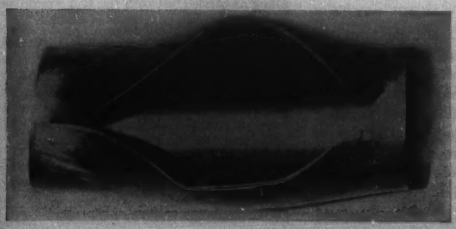

Figure 11. Pressure-test rupture of pipe made by new technique

after bursting the fracture is examined for location along the pipe, the position with respect to the welds, the nature of the fracture, and the uniformity of crystal size. In addition, a slug of lead from each press, following the extrusion of the pipe, is cut in sections and etched as shown in figure 5 as a check on the technique of cylinder filling.

This technique of filling the cylinder completely eliminates the so-called critical region from a pipe. Figure 6 shows an etching of a ring taken about 30 feet from the beginning of a pipe and in the zone of what is normally considered the critical region. When compared to figure 3 one readily notes an improvement.

Table III. Chemical Corrosion

Time in Hours in Boiling Distilled Water	Type of Lead Sheath, Specimen Approximately 150 Grams		Milligrams $Pb(OH)_2$ per Gram of Lead
25	St. Joseph	Untreated	0.049
		Treated	0.027
70	St. Joseph	Untreated	0.064
		Treated	0.042
112	St. Joseph	Untreated	0.089
		Treated	0.068

In view of the intense chemical activity of metallic sodium in the presence of moisture or chemical solutions which are known to attack lead, comparative corrosion tests were conducted on treated and untreated metal. Since corrosion is largely of an intercrystalline nature the extent of corrosion will, in a measure, depend upon the purity and general characteristics of the intercrystalline material, or we may say the cementing medium. According to Dunsheath,[6] this cementing medium is generally made up both of amorphous and crystalline metal, with the former predominating. It is this boundary material which is readily susceptible to corrosive conditions, particularly when the metal is under stress.[6] Since sodium treatment brings about stabilization not only to the crystals but also to the intercrystalline cement as well, it is expected that better bonding between crystals, greater stability, and less susceptibility to corrosion should result.

A series of corrosion tests were made to compare the rate and degree of corrosion on treated and untreated lead. Both types of lead were exposed to live steam at 105 degrees centigrade for 100 hours. The treated lead disclosed a white deposit of lead hydrate, $Pb(OH)_2$, which could be readily rubbed off. The untreated lead had a brownish white deposit on the surface which was hydrated lead monoxide $PbO.Pb(OH)_2$. The latter was quite pronounced, embedded in the surface, and required a sharp tool to remove it.

In another experiment 2-inch squares of lead sheath, approximately 150 grams in weight, after being thoroughly sandpapered, washed with distilled water, and wiped dry with a soft cloth, were placed in 500-cubic-centimeter porcelain casseroles, submerged in 300 cubic centimeters of distilled water, and boiled for varying periods of time, ranging from 25 to 112 hours. At the end of the respective periods the solutions were tested for alkalinity by titrating with a one-tenth normal solution of HCl, using phenolphthalein as an indicator, and calculated to milligrams of $Pb(OH)_2$ per gram of lead. The results are shown in table III.

It is to be noted that in all cases the water for the untreated lead showed a greater alkalinity than the treated lead. Moreover, when the samples were removed from the casseroles and allowed to dry, the deposit formed on the surface of the untreated lead samples was more pronounced and was whiter in color than on the treated samples.

In addition, corrosion tests were made on samples of both types of lead by differential aeration, using various kinds of chemical solutions which are known to be met in actual service. Nine samples of lead pipe, 1.75 inches over-all diameter and 6 inches long, with the solutions were placed in one-quart glass jars and the pipes were partially submerged by setting the jars in an inclined position. The results of these corrosion experiments as indicated by the amount of acid necessary to neutralize the resulting alkalinity of the solutions are shown in table IV.

Table IV. Corrosion Due to Differential Aeration

Description of Solution	Cubic Centimeters of 0.066 n HCl Used to Neutralize Ten Cubic Centimeters of Solution	
	Untreated Lead	Treated Lead
Manhole water	0.3	0.3
Manhole water plus CO_2	0.9	0.55
Tap water plus CO_2	0.3	0.3
Tap water plus CO_2 plus one per cent acetic acid	47.5	45.0
n/10 sodium bicarbonate	15.4	15.2
n/10 sodium chloride	1.3	0.3
n/10 calcium sulphate	1.9	0.8
n/10 ammonium hydroxide	7.7	6.7
One per cent lime water	8.0	7.6

It is to be noted that when comparing both types of lead that the treated lead does not show any greater degree of corrosion than the untreated lead.

Considering the results of the experiments described above, it is our opinion that the corrosion resistance of treated lead is at least equal to, and somewhat better than, that of untreated lead.

Summary and Conclusions

The following conclusions may be listed as to what has been accomplished by the combination of the method of filling which we are using and the stabilization of the lead.

1. All types of deleterious impurities are removed in process of treating commercial lead with sodium within the critical range of 0.005 to 0.05 per cent sodium. Such treated lead will retain approximately 0.001 per cent residual sodium which has a stabilizing effect, when such metal is remelted, processed, and used in service.

2. In processing no special equipment is necessary, no extraordinary ingenuity is required, and no hazard in treating lead is involved.

3. With proper lead-press procedure, cable sheaths extruded from treated lead disclose a bright appearance, a distinct, uniform, and brilliant crystal structure, absence of flow lines, inclusions, and other commonly known defects.

4. Alloys prepared from treated lead are homogeneous and stable; moreover, the tendency toward segregation is reduced and thus greater resistance to corrosion is brought about.

5. Chemical corrosion tests show treated lead to be somewhat better than untreated lead.

6. Cable sheath extruded from treated commercial lead is in conformity with American Society for Testing Materials and Association of Edison Illuminating Companies requirements.

7. A cable sheath of stabilized metal is available, which throughout its entire length is free of occluded and dissolved gases, various oxides, sulphides, and other foreign matter.

8. A stabilized cable sheath has been developed whose metal can be remelted and maintained at elevated temperatures, such as 900 degrees Fahrenheit, in an open pot for long periods of time without drossing or affecting its chemical or physical characteristics.

9. By means of treated lead and bottom filling as carried out with the Hill standpipe complete welding of charges is assured.

10. The appreciably greater fluidity and higher temperature of treated metal is a distinct advantage as it not only helps to float to the top of the lead-press cylinder any foreign matter, but makes it much easier to fuse the old and new charges and thus facilitates the welding operation.

11. In the long-time pressure test on full-charge lengths, treated lead sheaths require invariably a higher pressure and disclose a knife-edge break at time of rupture.

12. It cannot be overemphasized that the lead-sheath problem is both a mechanical and chemical one. If improved quality of lead sheaths is to be expected, then our method, or some other method that will bring about the same result, is necessary.

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Discussion

Lyall Zickrick (General Electric Company, Schenectady, N. Y.): I have studied with quite some interest the preprint copy of the paper "A New Technique for Lead Cable Sheathing" by Reinitz and Wiseman.

The authors are to be commended for their efforts and endeavor in attempting new improvements for the cable manufacturing industry. There are contained in the paper, however, several items which it would be well to have the authors further clarify. For convenience, these items may be listed as follows and taken up in detail:

(*a*). References to the work of other investigators.

(*b*). Comments on the method of filling.

(*c*). Regarding quality of lead and effect of sodium.

(*a*). In the authors' references to the work of other investigators it appears that considerable detail has been omitted from the report which would justify their conclusions. Inasmuch as these references to the work of others are quite critical, substantiating data would seem desirable. I know in our work with hydrogen there are both effective and ineffective ways in which it may be applied. There is no doubt about the ability of hydrogen to reduce lead oxide when applied correctly.

(*b*). In reading the description of their method of filling, I have been wondering if the authors experience any difficulty in getting a good well-fused area between the new and old charge. We were successful with some of our early methods in obtaining a well-fused area in the central portion, but not clear to the edge. We now obtain an excellent bond clear to the edge and for about three to four inches into the old charge.

Table I

	Per Cent		
	(A) Southeast Missouri Desilverized Lead	(B) Very Pure Lead	(C) Southeast Missouri Undesilverized Lead
Silver	0.0004	0.00000	0.0068
Arsenic	0.0001	0.0000	0.0000
Antimony	0.0012	0.00024	0.0010
Bismuth	0.0012	0.0000	0.0005
Copper	0.0003	0.000057	0.062
Iron	0.0008	0.000193	0.0003
Zinc	0.0007	0.000080	0.0002
Manganese	0.0000	0.0000	0.0000
Nickel and cobalt	0.0000	0.0000	0.0048
Total of above impurities	0.0047	0.000570	0.0756
Lead by difference	99.9953	99.99943	99.9244

(*c*). Throughout the text there are a great many references made to the quality of pig lead which appear to be quite alarming. One gains the impression that the so-called good brands of lead we cable manufacturers use are full of, to quote: "entangled oxides, sulphides, and other deleterious impurities", and again "such deleterious compounds as sulphides which are usually present in commercial lead", and still again I encounter the phrase, "the oxides in solution."

I feel it would be especially desirable for additional enlightenment on this subject, for if such is the quality of lead we use, the industry should be so informed.

For my own part, I have never found any evidence of any solubility of oxides in lead, either in the literature or elsewhere, and the same is true as well for sulphides. If these so-called impurities are soluble, I would not expect them to segregate, especially to the grain boundaries as stated, at least until they had precipitated from solution.

Again in the text an implication has been made which suggests an excessive amount of dross in pig lead. Reference 13 to the work of D. M. Smith has been quoted. Smith's work gives no information whatsoever as to the source, type, or chemical composition of the lead he used, but merely states that upon melting in vacuum he obtained a quantity of dross, which to quote directly from his work: "Spectrographic analysis showed that this dross consisted mainly of lead, small quantities of tin, calcium, aluminum, magnesium, cadmium, and carbon also being detected." It does not appear reasonable to classify the above as being in any way representative of our pig lead of the present day, produced by reliable refineries. I believe the lead we use is of far better quality than is herein intimated.

I am somewhat confused as to the part or metallurgical function the sodium addition plays, especially the residual sodium.

In general, I believe it is accepted that the purer the lead is the lower the tensile properties, and also to a degree the larger will be the grain size and the lower the resistance to fatigue. For illustration, the data in tables I and II of this discussion are pertinent ("Pure and Low-Alloy Lead", a paper by G. O. Hiers presented at an AIME symposium on pure metals, February 1939).

In table II you will note the low physical properties for lead 99.9994 per cent pure. If such is the case, the action of this small amount of residual sodium scarcely seems to be in the direction of greater purity.

Again I read "untreated lead stretches faster than the treated metal because of the improved crystal bond that is characteristic of the treated lead, which reduces that part of the flow which is associated with the crystal boundaries."

In metallurgy the nature of crystal boundaries and their characteristics has for years been a subject for controversial argument and discussion. It seems the subject can hardly be so easily and lightly dispensed with. The inference is that lead flows along crystal boundaries at least to a degree, and because of this treatment such flow is retarded. It is common metallurgical knowledge today that the precipitation of a phase from solution causes such a stiffening of crystal boundaries, so here again a higher degree of lead purity is not indicated. Precipitation may occur throughout the crystal,

Table II. Hardness and Tension Tests of Cast Metal

	(A) Southeast Missouri Desilverized (7)	(B) Very Pure Lead 3712(5)	(C) Chemical Lead (10)
Yield point (0.5 per cent elongation) (pounds per square inch)	861	714	1,643
Ultimate tensile strength (pounds per square inch)	1,966	1,609	2,765
Elongation (per cent)	64.2	68.6	50.2
Reduction in area (per cent)	92.4	100.0	87.9
Brinell hardness number one hour after casting	4.2	2.9	5.5
Brinell hardness number ten days after casting	4.1	3.0	5.4

but time and aging tend to agglomerate the precipitated phase in the grain boundaries. Could not this strengthening effect be due to precipitation of a sodium-lead phase originating from the residual sodium? Long-time aging tests (two years or more) taken on sheaths containing varying amounts of residual sodium should give important data covering the effect of this constituent on fatigue, corrosion resistance, and other physical properties.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): For a given kind of lead or lead alloy, the two main desirable characteristics of the sheath from the standpoint of the user are (*a*) soundness of structure and (*b*) circumferential uniformity of thickness. The authors' paper relates to the first characteristic.

As indicated in my discussion on expansion of sheaths on underground power cables in service in the University of Illinois Bulletin 306 mentioned in reference 1 of the authors' paper, imperfect welds and nonmetallic inclusions usually constitute the initial set of causes for a large number of openings of sheaths at defects in service. After about five years of operation, openings have occurred in Chicago at a high rate also in abnormally thin portions of sheaths. Most of these unfortunate occurrences in Chicago obtained for 66-kv solid-type single-conductor cable, the number of defective lengths of this type of cable involved having been close to 200 to date. Over 4,000 lengths of such cable were installed, principally during the period of 1926–31, inclusive.

Sheath troubles due to inherent defects have also occurred to a lesser extent with, for example, 4- and 12-kv cables which have relatively less insulation. Also, such cables have joints filled with a heavy viscous compound whereas the 66-kv cable had joints filled with a thin oil under a small pressure. The oil migrated into the cable and resulted in the maintenance of relatively high internal pressures during the periods of daily maximum loads. The resulting rate of sheath expansion has been excessive (about six mils in diameter per year) and so investigations are being conducted to devise a scheme to reduce sharply this rate in order that a reasonable cable life may be obtained.

In view of all our trouble, it is obviously very gratifying to have learned of the improvements described in the paper. Cable with sheath treated as outlined in the paper has been furnished to Commonwealth Edison Company and no structural defects have been found in such sheaths.

The authors refer to tests to rupture and to creep tests at 500 and 850 pounds per square inch. Such data are of general interest, but more pertinent data are those obtained at lower stresses which apply for most operation. Obviously, a sheath that expands unduly is quite undesirable and the cable may develop trouble long before rupture of the sheath occurs. The authors, I believe, appreciate this point because the manufacturer has co-operated with me by furnishing samples for long-time creep tests to be made at the University of Illinois under the sponsorship of the Utilities Research Commission. In these tests of treated lead, the samples of ASTM grade II lead and of ASTM grade III lead had creep rates within the range found for similar materials having no treatment.

Perhaps a word should be said also for some of the other developments on cable sheath. We have had a large operating experience and have obtained a large amount of test data on samples of such sheaths furnished by other manufacturers. The progress made by the various manufacturers toward always furnishing sheaths that are structurally sound has varied, but nowadays it appears that very good sheaths are being produced by some of the methods that the authors tried and found wanting.

Any of the methods used by the manufacturers must be accompanied by continuous good workmanship to assure uniformly perfect sheath structure, and the cable manufacturers are aware of this fact.

I. T. Faucett (General Cable Corporation, New York, N. Y.): The authors cover a very broad subject on which the industry has made large expenditures in research and development during the past decade. Essentially, the method which they recommend for obtaining uniformity of lead structure is to offset the effect of one impurity by the introduction of another. It would seem that the preferred approach to the problem is to exclude the impurities in the first instance, as is done, for example, in the vacuum press.

Among the recognized causes of field troubles with lead sheaths is the oxidation of ram lubricant. This is not mentioned in the paper, and it would be very interesting to know how this dangerous impurity is eliminated in the authors' process.

Another cause of trouble with lead sheath, common to most methods, is the chilling of the lead ram, molten lead, and cylinder walls during the charging of the press, as well as the oxidation incident thereto. As the ram moves out of the cylinder, air is allowed to enter and this not only chills the ram and cylinder walls but also chills and oxidizes the surface of the lead remaining from the previous charge. The Hill standpipe method, used by the authors, is subject to the above condition. The vacuum press, on the other hand, eliminates this source of trouble by providing a closed evacuated system into which the lead is introduced through an electrically heated pipe. In the vacuum press, oxide is not given a chance to form, whereas the authors' method depends upon the reduction by means of sodium of the oxides which must inevitably form and the subsequent skimming of the sodium oxide, which is not positive.

The authors refer to the vacuum press and state that:

"... while the vacuum press will remove free gases during the filling of the cylinder and thus eliminate oxidation in this respect, it cannot reduce entangled oxides, decompose sulphides, or eliminate other deleterious impurities already present in the lead in the melting pot. Such impurities are to some extent soluble in and occluded by the molten metal."

The authors state they have not investigated the vacuum press and apparently they are unaware of the method used in the melting of the lead in the lead kettle and the drawing of the melted lead into the lead cylinder. In the vacuum press the lead is melted in a basket located one-quarter of the height of the kettle from the top and the lead is drawn out at the center line of the kettle one-quarter of its height from the bottom. This procedure prevents any entangled oxides and other insoluble impurities from being carried toward the bottom of the kettle, because such impurities, due to their lower density, will float and further, because the melting is done at the top of the kettle. With this arrangement only pure bright metal can go over into the lead-press cylinder.

With further reference to entangled oxides and sulphides, it should be noted that the alkalies used in standard refining methods are as effective in removing sulphur as is the sodium treatment. This, together with information from precise tests, shows that sulphides are not part of the impurities unless incompletely refined or contaminated lead is used. As for the presence of oxygen, some of the leading metallurgists contend that it is not present in significant quantities. However, even granting that the sodium reduces or removes in the melting pot dissolved or occluded oxides, it would seem from the authors' description of their process that the molten lead must again be pretty thoroughly exposed to the action of the air and with a new opportunity to entrain or occlude oxides. How is this prevented unless there is present in the final metal considerable controlled amounts of sodium? Is 0.001 per cent of sodium supposed to be adequate for this, and, if it acts in this way, does it continue to exist in that quantity, regardless of detail of procedure?

The authors state that although sodium is present in the final product, it does not become alloyed with the lead. This statement is open to question, as metallurgical literature indicates that sodium may be in solid solution in lead in quantities comparable to those used by the authors. However, whether the sodium is present as an alloy or as a mixture, a much more careful and complete study of physical and chemical properties than is indicated by the authors seems warranted. Concerning the chemical properties, it is interesting to note that the authors conclude that their corrosion tests are favorable. In the long run, extended field experience will be the only sound criterion, particularly as there are so many factors influencing corrosion, other than those investigated by the authors. In particular, there must be assurance that the corrosion data obtained are with samples containing the maximum amount of sodium which may ever be present in actual commercial production.

The authors' test results are a case in point. It is noted that the treated lead had a white deposit which was readily rubbed off, whereas the deposit on the untreated lead had to be removed with a sharp tool. Contrary to accepted belief, this is suggested as an advantage of the treated lead. Lead owes its corrosion resistance to the formation on its surface of an adherent nonsoluble protective film. Chemical corrosion of lead in service occurs only where the conditions are such that the film is either soluble or nonadherent. It would be of interest if the authors would offer some explanation concerning their apparent belief as to the advantage over a strongly adherent film of one which could readily be rubbed off.

Data are given for tensile strength, elongation, hardness, bending tests, corrosion, and creep. Most of the differences shown are within the degree of experimental error

found in such tests and are not therefore of any importance other than to show that in these samples the sodium has not impaired the physical characteristics of the lead. As with other metals, the physical properties (ultimate state of equilibrium) of lead are affected by previous physical and thermal history and therefore some variation in these properties in different samples must be discounted unless the treatment of the lead is adequately controlled. On the other hand, if definite changes in the properties of the lead were found, may not these be due to the effect of the sodium as an alloy? If the change is due to the presence of the sodium, how do the properties depend upon the amount of this alloying constituent?

The condition shown in figure 10 is, we believe, not pertinent to present-day practice. With the condition of the nonunion of charges shown in figure 2 and the microstructure of extruded pipe shown in figure 3, it is natural to expect the rupture in the weld shown in figure 10. However, although these conditions may have existed five or six years ago, they are not representative of present-day practice and are definitely not those found in pipe made by many of the methods discussed by the authors.

The authors in their conclusions 3 and 4 state in effect that the structure of lead sheaths produced by their method is uniform and free from flow lines, also that the tendency toward segregation is reduced. It should be borne in mind that structural uniformity and freedom from flow lines are entirely relative, that is, some extrusion processes will result in less prominent flow lines than others, but in all cases flow lines and welds in the charge-weld region can be detected by proper etching methods. Flow lines and welds do not mean that the sheath is defective and tests prove that unless foreign inclusions or dimensional deficiencies are present, the weld usually will be as strong as the metal outside the weld region.

Bearing on etching methods, some experience which we have had in examination of lead sheets containing small quantities of sodium may be mentioned. So far as concerns ordinary behavior in the laboratory, this lead seems to tarnish no more and no less than similar lead without sodium. However, attempts to produce photographs of etched surfaces of lead containing sodium have met with great difficulty due to the tendency of the etched surface to tarnish much more rapidly than with any other lead or lead alloy with which we have worked. Because of this tarnishing or oxidation, photographs of the etched surfaces could be obtained only by a more refined etching technique than required for other lead surfaces.

A word on the control of the process is in order. Definite and simple control is of paramount importance in order to insure perfection in any product. With the vacuum lead press, control is very simple, since a vacuum gauge tells the whole story. If the vacuum is good, the results must be good. In the authors' method, however, the matter of control seems to offer great complications. In this connection, the following points may be considered:

(*a*). The authors indicate that a range of 0.005 to 0.05 per cent of sodium by weight (0.06 to 0.6 per cent by volume) may be used depending upon the impurities of the lead to be treated. Has any precise method been worked out to predetermine the amount required for lead from different sources and containing different impurities?

(*b*). What is the effect on the stabilising properties if the sodium as poured into the press, varies from the normal amount?

(*c*). Have the studies of the physical and corrosion properties of the extruded lead been correlated with the final amounts of contained sodium or have these studies shown that the control of the amount of sodium used is unimportant?

(*d*). Figure 4 indicates that no means are provided to prevent air from entering the standpipe and to keep the pipe full of lead. Are such means provided? If not, is there not thorough mixing of the lead stream with air during the flow? Will not oxides formed be carried down to the bottom of the charge where they may be caught on the cylinder walls before rising to the top? Does the standpipe remain clean and bright, or does dross from the surface of the poured lead cling to it as it is removed?

D. M. Simmons (General Cable Corporation, New York, N. Y.): I like this Reinitz-Wiseman paper because it is such good publicity for the vacuum press which has been developed and is used by our company in all our paper cable plants. Moreover, the processes described in this paper actually do result in fairly good lead sheathing—though not, we are confident, as good as is obtained with the vacuum press. Consequently, in criticizing parts of this paper, the criticism is made not with the thought of unfavorable comment upon the resultant product, but rather is the criticism directed toward some of the theory and analysis, and toward some of the criticisms of other methods.

These authors have contrasted their present results with the worst results obtained in the past, obtained by methods now generally abandoned, and they would lead the reader to understand that only with their method can good results be obtained. The analysis by which they attempt, in the absence of experimental information, to establish this conclusion is the object of our criticism. Several different aspects of their analyses will be considered.

They describe the use of sodium in connection with lead which they describe as being very bad in respect to dross formation. They have apparently not recognized that excessive dross formation on lead is likely to be a result of contamination by certain metallic impurities present in exceedingly small amounts, such as antimony, etc. The sodium treatment, in addition to reducing the lead oxide formed on the outside of the pigs, happens also to be an effective means of eliminating these troublesome metallic contaminations. The rate of dross formation is so greatly reduced that, by contrast, the metal may, now, seem to retain a silvery surface. Also there may be enough sodium hydroxide formed to contribute a colorless slag still further helping to maintain a bright surface. The "stabilization" of the lead in the melting pot is thus very simply explained.

If these authors were using a lead with such bad drossing characteristics and were using this under conditions such as were common in lead covering some years ago, it is not surprising that there was excessive dross formation and excessive oxide inclusions in the sheath which was produced. The Hill standpipe method would not eliminate the formation of dross as the lead was passed into the cylinder and the excessive dross formed in the melting kettle itself may have found its way into the lead press. Accordingly, there was an exceedingly bad condition which undoubtedly was relieved considerably by the refining operation which this particular lead demanded.

Also, in reference to the appearance of the pigs of remelted lead, it should be noted that commercial lead is normally stored outdoors and subject to considerable surface oxidation and that any properly remelted lead stored inside will be much brighter and more silvery in appearance and will remain much brighter than commercially handled pigs as long as this lead is protected indoors.

Published data indicating the presence of appreciable amounts of oxygen in lead are not accepted by some of the best authorities on the metallurgy of lead. Also, we have authoritative assurance from one large refiner of lead that sulphur does not exist in any of their brands of lead even to the fourth decimal place. In view of the perfectly rational explanation of the experiences with dross formation on the basis of accepted causes (metallic impurities) the authors' explanation of the effect of the sodium is not very plausible.

It is noted that they found the Hill standpipe method of filling inadequate until combined with the sodium refining of the lead. In view of their comment about the bad drossing characteristics of the lead which they were using and in view of certain fundamental difficulties with the standpipe method, it is readily seen why there should be difficulties with drossing. Oxides formed on the surface of the high-temperature molten lead would rise partly to the surface of the molten lead but other portions of the dross would attach themselves to the sides of the lead cylinder. Oxide would also be found on the inner and outer walls of the pipe, especially if this was kept at a high temperature so that the initial pouring would be at high enough temperature to melt the surface of the previous charge. Altogether, there would be plenty of reason to expect trouble with oxide inclusions in spite of any gain which might have been obtained as a result of the surface melting of the previous charge.

Along with the vacuum process of filling the lead cylinder, we have combined other refinements of operation as described earlier by Mr. Faucett in his discussion and resulting in the filling of the cylinder with dross-free lead under vacuum conditions not conducive to the formation of any additional dross.

Howard S. Phelps (Philadelphia Electric Company, Philadelphia, Pa.): This paper is one of many evidences of the excellent work done by the cable manufacturers in recent years in response to the demands of cable users for improved lead cable sheathing. The technique described is undoubtedly capable of producing sheathing of a quality superior to that generally available a few years ago. However, it does not deal with the entire problem. Accordingly, there is reason to doubt if the results from it really are superior to those of several other improved techniques already in use.

In considering the problem of obtaining satisfactory lead cable sheathing, it must be realized that, except in the use of European continuous-extrusion machines, there are two distinct weld areas that are potential sources of trouble. These are: (1) the

weld between charges, which gives rise to flow lines; and (2) the die weld, or welds, formed as the two streams of lead meet after passing over the bridge of the die block. The paper by Messrs. Reinitz and Wiseman deals exclusively with the former and ignores the latter.

Analyzing the reasons that support the advantages of uniting the successive charges without welds reveals they are equally important in respect to the die welds. That portion of the description of the new technique concerning the uniting of successive charges stresses the importance of melting the surface of the old charge to facilitate its complete union with the new one. The procedure of introducing the lead of the new charge at a higher temperature, and of directing its flow over the entire surface of the preceding charge, undoubtedly helps accomplish this.

However, the new technique makes no provision for improving the union between the two streams of solidifying lead after passing over the bridge of the die block. Accordingly, the die weld probably remains as weak in the new as in the old technique.

It is fair to conclude that even if one of the two sources of trouble is completely removed, the over-all improvement in quality of the product ceases when the charge weld area has been made as strong as the die weld area. Therefore, it would seem that any technique accomplishing this objective is substantially as good as another.

The foregoing observations apply in particular to the relative merits of the Hill standpipe method of filling the press, rather than to the advantages claimed for the chemically stabilized lead. The latter advantages are not readily apparent from the test data reported.

From table I, the tensile strength of both "electro" lead and "electro" lead plus 0.01 per cent lithium is greater for the sodium treated than for the untreated. However, the reverse relation is true for St. Joseph lead and St. Joseph lead plus 2 per cent tin.

Further inconclusiveness appears in the creep data of figure 7 for the strip specimen at 500 pounds per square inch longitudinal stress and figure 8 for the pipe specimen at 500 pounds per square inch hoop stress. In the former case the treated lead has a greater creep rate while in the latter case it expands less.

These inconsistencies seem to indicate that the differences noted in test data may be a function of the type of lead tested or method of making the test, as well as the process of treating the lead. Certainly the published test data do not convincingly establish the superiority of sodium-treated lead.

The strongest apparent case in favor of the sodium-treated lead is the evidence reported about the type of burst. However, comparing this evidence with that of other independent tests, the reported results are still inconclusive.

For several years, the Philadelphia Electric Company has been studying types of burst in lead cable sheathing, as disclosed by stress-to-failure tests. The results have indicated that extreme caution must be used in drawing conclusions from short-time tests.

It has been found that short-time tests at relatively high stresses result in wedge-shaped fractures that develop from gradual necking down of the lead. On the other hand, for long-time tests at much lower stresses, it can be stated generally that when either die welds or flow lines are involved, the sheaths fail by fractures that develop abruptly without necking down; apparently from a separation of the lead crystals at a weld. For tests at either short time and high stress, or long time and reduced stress, the exact type or character of sheath failures appears to depend on such factors as temperature of sample during test, unit stress in the material, and the composition of the lead being tested, in addition to the success of the weld.

These observations have been found true regardless of the technique for recharging the lead press, or method of purifying the lead. It remains to be seen from actual tests under carefully controlled conditions whether or not the characteristics under discussion will have been improved in the case of sodium lead.

W. H. Bassett, Jr., and **C. J. Snyder** (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): Messrs. Reinitz and Wiseman have presented a very interesting paper describing the developments which they have undertaken in the Okonite laboratories. In evaluating the results presented, it is suggested reference be made to our paper "Occurrence of Irregularities in Lead Cable Sheathing and Their Relation to Failures," published in the *Transactions* of the American Institute of Mining and Metallurgical Engineers, 1933, volume 104, which is not included in the bibliography in the paper. In this paper we described how uniform cable sheath can be produced by good foundry practice. A number of micrographs of cable sheathing were shown similar to the authors' illustrations, figures 3 and 6. We fail to see any appreciable difference in the structure of the cable sheath resulting from Hill standpipe filling, the authors' figure 6, and the structure of cable sheath produced by our good foundry practice, figures 1, 2, and 3 of this discussion.

We have investigated bottom pouring of lead and have found that it is advantageous in the production of satisfactory calcium-lead-alloy cable sheath or other types of alloys which oxidize rapidly. We have likewise investigated the fusing of the remainder of the old charge to the new charge in the lead cylinder. (For details of movement of lead during extrusion cycle see figure 4 of this discussion.) We have found

Figure 1. Structure of section of carefully prepared lead tube 21 feet from start of extrusion cycle

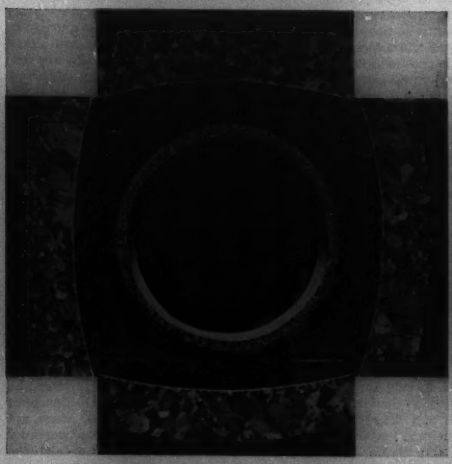
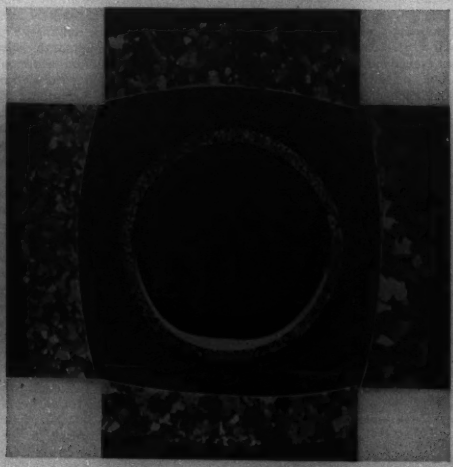


Figure 2. Structure of section of carefully prepared lead tube 28 feet from start of extrusion cycle



that this fusing is not necessary nor essential, nor is the bottom pouring required when producing common or copper-bearing lead cable sheath. Bottom pouring of castings is an old and useful foundry practice, but cannot be used universally. We have found that there are some grades of lead which cannot be handled by the bottom-pouring method as this practice produces at one location in each extrusion cycle a structural condition in the lead sheath which results in abnormally low tensile strength.

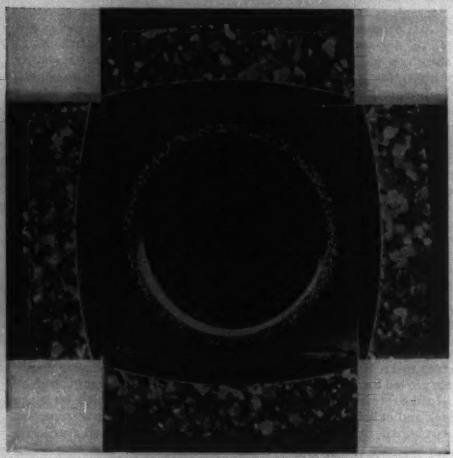


Figure 3. Structure of section of carefully prepared lead tube 77 feet from start of extrusion cycle

The quality of a product can be judged only by the results of tests on the finished material which naturally must be free from weak spots. If, as the authors point out, the two charges do not weld together under the heat, pressure, movement of the lead through the cylinder, and the subsequent hot working in the die block, then laminated and blistered sheath would be produced. With the proper technique at the lead press, optimum results are obtained. The term "good foundry practice" as used by the writers refers to the selection of the lead, the melting conditions, the control of the pouring temperature of the lead, bottom pouring, if required, the skimming or cropping operation, the pressure on the lead during the cooling cycle, and the speed and temperature used during the extrusion cycle. We also see that the lead is not contaminated with oil or grease, air or moisture, and, in other words, that all conditions are correct for the casting of a sound billet in the cylinder so that homogeneous lead sheath is produced.

We are particularly interested in the authors' results of internal pressure tests on full-charge lengths of pipe extruded under normal production conditions. In these tests the sample is subjected to 90 pounds per square inch (805 pounds per square inch hoop stress) for ten days, then the pressure is raised ten pounds per square inch every five days until failure occurs. They state that many failures occurred in less than ten days when testing samples produced by their former extrusion practice.

We have made many full-charge bursting tests in the Anaconda laboratories. It has been our experience that all samples break with a knife edge fracture when tested above 100 pounds (1,000 pounds per square inch hoop stress) gauge pressure unless a definitely defective sample was used. We would therefore like to ask the authors what results they would have obtained if they had allowed the tests on their full-charge tests to continue at the original 90 pounds gauge pressure.

In our laboratories, where 2.75-inch outside diameter by 0.133-inch thick full-charge lengths have been tested at normal room temperature (65 to 85 degrees Fahrenheit) under a load of 85 pounds gauge pressure (850 pounds per square inch hoop stress), we have never experienced failures in less than 60 days. It is not unusual to require 90 days in order to reach a failure on a reel of ordinary copper-bearing lead.

We feel that the full-charge bursting tests should be carried to destruction at one pressure, because of the normal characteristic difference in appearance of lead failures at 90 pounds and 130 pounds per square inch pressure (900–1,300 pounds per square inch hoop stress). We have made tests where the pressure was increased in steps and have always obtained knife-edge fractures. It is possible therefore that the authors' test method may give misleading results.

The *Journal* of the Institute of Metals shows that sodium has been used in treating lead for nearly 20 years. In 1920 Thieme[1] reported the hardening of lead by the addition of sodium. In the same year Jones[2] reported good corrosion resistance in a chemical plant by the addition of sodium to lead. He attributes the good effect of sodium to the removal of oxide. Calingeart and Boesch[3] in 1923 report a correction to the lead sodium equilibrium diagrams published by Mathewson[4,5] in 1905 and 1906. A recent patent[6] issued to Magill of Du Pont covers the addition of sodium to lead in order to produce an alloy which is more rapidly corroded than pure lead. The application of this alloy is in the manufacture of white lead or any other operation where the lead is to be dissolved by some corroding agent.

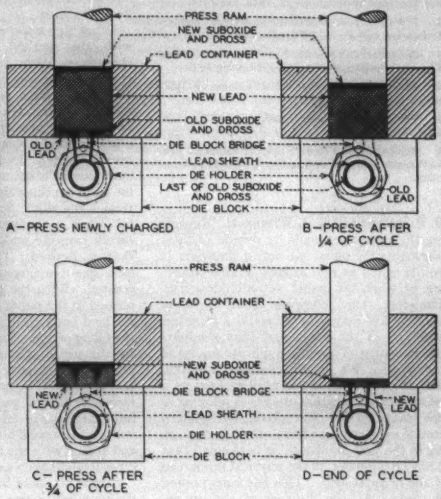


Figure 4. Probable movement of lead oxide and dross as indicated by following sections from extrusion cycle

In our early studies of the production of lead cable sheath, we recognized that certain brands of lead made more dross on remelting than others. This subject was discussed with the Anaconda refinery, and, in 1932, they developed a special grade of lead which gave a bright surface on remelting. The refining experts report that the importance of sodium is in the removal of impurities from the lead. On remelting lead which has a relatively low antimony content, we have found that a mirror surface can be obtained. For example the difference in behavior of lead pigs *A* and *B* illustrated below can be readily noted:

Pigs Marked	Lead	Per Cent Copper	Bismuth	Antimony	Silver
A	99.850	0.067	0.072	0.0096	0.0013
B	99.870	0.061	0.065	0.0007	0.0029

In working with calcium lead in 1935, we found that the dross-forming elements were

removed from the lead and that on remelting the lead surface remained bright in the same manner as reported by the authors with respect to sodium.

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B. B. Reinitz and R. J. Wiseman: Reviewing the comments made by several of those discussing the paper, we note a similarity in points raised as well as lack of understanding of what the paper actually describes. Therefore, the following restatement of several facts may help to correct a misinterpretation of the paper and thus eliminate the necessity of making duplicate replies to comments. We do not consider the addition of sodium in the quantities used as a refining or purification process or alloying of the lead. In the first place, the amount used is very small and the quantity remaining in the lead for sheathing is so small that it has no influence on the physical properties of the original lead. This has been proved by tests. As the amount of sodium remaining in the lead is of the order of 0.001 per cent to 0.002 per cent and far less than that of other foreign metals which the lead may contain in the brands of commercial lead used at present for cable sheathing, it is hard for us to understand why it is thought we are alloying when, as we state above, our process does not change to any extent the physical properties of the lead. In other words, we do not contaminate the lead, we do not endeavor to make the lead harder, nor do we increase its vulnerability to corrosion. As the cable specifications allow a total of 0.15 per cent of metallic impurities in the lead for sheathing purposes, and we normally are well within this value, the process does not cause the chemical composition to be materially changed from a commercial viewpoint. We do not try to improve the chemical composition, that is, by the addition of sodium, no attempt is made to reduce the quantity of other metals present in lead as some refiners have done in the past when they added as high as three to seven per cent of sodium and using entirely different processing methods. We purposely use only sufficient sodium to cause the oxides and sulphides which are already present, or the oxides formed during heating, to decompose or to be thrown out of solution. We call these the deleterious impurities, as distinguished from the metallic impurities. Our treatment is quite limited in this respect as otherwise we would get into the same difficulties of corrosion that others have experienced where larger quantities of sodium are used. It was the discovery that it is the extremely small amount of sodium which prevents oxidation and removes the oxides and sulphides which makes this process of value. Metallurgically, purification and refining consists in reducing the amount of metallic impurities. We do not consider our process as such, but rather look upon it as a cleansing and stabilization, what might be called a scavenging of the nonmetallic impurities which, heretofore, have not been properly recognized as one of the major causes of the defects in lead sheathing.

Using this improved lead in combination with the method described for uniting charges, a better lead sheath is obtained. Our tests and customers inspection reports extending over a period of years have all indicated this. We believe, and, as stated in the paper, "that this method or some other method which brings about the same results, namely elimination of flow lines and laminations, is necessary," if we are to hope for lead sheaths which will give a longer life than in the past. Some of the methods used by other manufacturers only accomplish certain specific ends instead of everything that is desired. The vacuum press and hydrogen-flame treatment are notable in this respect. With the treating of the lead described in the paper not only is oxidation of the lead both in the melting pot and during the filling of the cylinder prevented but also, by the use of the standpipe, we actually cause the successive charges to be 100 per cent united. This has been proved by many tests over several years. In these tests, the full charge in the lead block and cylinder is removed as a solid block, cut in half, planed, and etched with the lead consistently giving cross sections such as shown in figure 5.

Comments have been made that perhaps we have been using inferior brands of lead and that something must be done about it. Such is not the case. Like other manufacturers we purchase the standard commercial brands of lead required to meet ASTM specifications. For the purpose of this paper, in order to emphasize what can be accomplished by such treating of the lead, we took (1) St. Joseph lead which everyone acknowledges is one of the highest grades of commercial lead, and which drosses to the same degree as other brands, and (2) electrolytic lead which is of a higher commercial metallic purity but oxidizes more readily. This shows that this treatment greatly improves all kinds of commercial lead from the standpoint of oxidation and at the same time does not adversely upset the other properties of the lead.

It has been suggested that a more elaborate list of references be given. As with most papers, more could be given if one wishes to take the space for them. We included those which we felt would cover the subject matter sufficiently for those who cared to go into it further. We wish to acknowledge the paper by Mr. Bassett in the *Transactions* of the AIME which reviews very well the lead problems which have confronted cable manufacturers in recent years.

We agree with Mr. Halperin that imperfect welds and nonmetallic inclusions usually constitute the initial set of causes for sheath failures. We remove the nonmetallic inclusions by the stabilization of the lead and eliminate the imperfect weld by our method of filling. What is at times considered as a defective die weld might be a poor charge weld where the laminations resulting from the nonunion of charges abutt the die weld. At times the charge weld is only about $^1/_{16}$-inch from the die weld and cannot be seen except by magnification after etching. In view of the above it is many times mistaken for a die weld.

It is recognized that more or less sound cable sheaths are extruded now by some cable manufacturers. However, it is the consistency of good foundry practice throughout the cable length that is essential, and not at the ends or scattered along the reel lengths. By the method described in the paper we are able to control, at all times, both the condition of the lead and the elimination of flow lines and laminations.

We are not able to agree with Mr. Bassett that the fusing of the successive charges is not necessary nor with his statement that some grades of lead cannot be handled by this method. Our studies have clearly shown complete fusing is essential if it is desired to eliminate flow lines. Careful examination of figure 1 which Mr. Bassett submits will disclose a flow line in the so-called critical region where metal from the vicinity of the contact of the two charges in the cylinder extrudes as pipe. We have used different grades of lead and tests have not shown low tensile strength.

In a manufacturer's laboratory it is necessary to obtain results in a reasonably short time, though long enough to be able to produce results comparable to service conditions. We believe this is accomplished by the pressure-time step test which we make on full-charge lengths of empty pipe, as, early in our studies, we obtained small slits in the pipe such as occur in service. The time taken for test is empirical and as the same method is used all the time we are enabled to compare the results. Answering Mr. Bassett on what would have been obtained if we had allowed our tests to continue at the original 90 pounds gauge pressure, we would expect it to continue for months before rupturing. Leaving samples under test so long does not help in completing a research in a reasonable length of time, nor is it an aid to learning whether improvements are being made. After a test has been completed and microscopic examination of the lead in the vicinity of the rupture has been made one can tell whether there were any defects in the pipe to have caused an earlier rupture than would otherwise occur.

Our review of the literature on the use of sodium in the treatment of lead shows that it has been used for about 50 years. However, the amount, form, and method have been distinctly different from the procedure described in the paper. Moreover, purification of the lead from foreign metals was attempted rather than the cleansing or stabilization from nonmetallic inclusions. Refining experts were only interested in removing metallic and not nonmetallic impurities, and, therefore, failed to appreciate how small quantities of sodium could remove oxides and sulphides, equally as objectionable as metallic impurities.

We do not agree with Doctor Simmons regarding the effect of metallic impurities on dross formation. The amount of sodium that we use does not eliminate metallic contamination nor is sodium hydroxide formed to contribute a colorless slag.

Where cable manufacturers may be criticized, is for their failure in the past to recognize that all brands of lead will dross. It seems to have been accepted as a natural

evil of little importance (the drossing is hastened in the melting pot and according to good foundry practice all manufacturers periodically cleaned out the red oxide) instead of finding means for the removal of this dross or oxides contained in the lead, as received, and seeing that further oxidation was prevented. Our process has accomplished this and it seems evident that no other process does the same. There have been improvements by some manufacturers in the lead-press operation, but not enough, and with no such treatment of the lead as the paper discusses.

The storing of lead outdoors and surface oxidation is not the whole story. Allow remelted lead to stand around and it will soon lose its luster, but this is merely a surface condition as there are still oxides dispersed through the lead.

The table herewith may help to show that sodium in the amounts that we use does not throw out other foreign metals from lead, that is, it is not a purification process. A quantity of antimony (0.07 per cent) was added to lead which was then heated to 850 and 1,200 degrees Fahrenheit, held at these temperatures for 30 minutes, and then checked for antimony content. The experiment was repeated for lead which had been treated with 0.02 per cent sodium. The results are as shown in Table III.

The time of treatment in the factory is much less than 30 minutes. It is the high temperature of 1,200 degrees Fahrenheit and not the sodium that reduces the antimony content.

We have relied too much on the statements of metallurgists on what is good or bad in lead. They confine themselves to the metallic phase of lead rather than realizing that the nonmetallic phase of lead may also be important. This was clearly shown by a refiner when he was told that we found sulphides in his lead. He first disagreed but after checking a sample confirmed our findings. Upon request that the sulphides be eliminated we were informed that commercially it would be too costly. That is, the refinement would not be justifiable in view of the small quantity of lead used for cable sheathing purposes as compared to general trade consumption. This seemed a logical reason and we thereupon set up our premelting pot to eliminate the oxides and sulphides.

We do not say that the Hill standpipe method of filling is inadequate unless its use is combined with the sodium treatment of lead. Rather, the paper shows there is a distinct improvement in the mechanical properties of a cable sheath through use of the standpipe but that it is desirable to go further by eliminating the oxides and sulphides in the lead, thus accomplishing a thorough job instead of a partial one.

We are in accord with Mr. Faucett that to overcome troubles it is necessary to eliminate the source of the trouble. The nonunion or nonfusing of successive charges is the cause of flow lines and laminations. These are eliminated by the use of the Hill standpipe method of filling the cylinder. The presence of oxides and sulphides in the lead are the source of weakness in crystal structure and our treatment of the lead overcomes this trouble. We think Mr. Faucett did not consider that the amount of sodium retained in the lead is far less than the amount of bismuth, antimony, arsenic, and copper which may be present and therefore the resulting lead composition is about the same as before it was treated.

There was no need of mentioning ram lubrication in the paper. We have not experienced the difficulties some others have had with it, even before the development of our new processes.

Chilling of the lead ram and cylinder walls is not of importance nor does chilling of the surface of the previous charge cause oxidation. Heat is the cause of oxidation, particularly if the lead is in a molten state. Our treatment prevents the latter from occurring while the lead is being poured into the cylinder and that is why it is so effective. Fundamentally, it is desired to have the successive charges to unite, heating of the ram or cylinder walls will not accomplish it. The surface of the residual charge must be melted and what better and easier way to do this than with the new charge so that the two charges are united as one. We question that the vacuum-press method unites charges and would be interested in seeing slugs similar to those shown in figure 5, to prove that it does.

As we view it, if an alloy of lead is formed by the addition of sodium, we should expect some physical or chemical change in the lead. It has been shown that we do not change the physical properties and, as far as we can tell, it is not in chemical combination with lead. The composition of the resulting mixture of the lead is still well within that expected in commercial lead, which may contain as much as 0.06 per cent copper, yet we do not consider this lead as an alloy in the commercial sense.

The amount of physical data which has been given on stabilized lead in the paper represents only a part of the tests already made and we consider these data sufficient to show that the process does not adversely change the properties of the lead. Regarding corrosion, we are fully cognizant that there are many factors which influence corrosion. It is also shown that the sodium treatment of lead does not intensify the corrosion rate of lead in solutions which are representative of those that occur in service. If unduly large quantities of sodium were used in lead, corrosion would then be very severe. The amount of sodium in the samples used for corrosion tests was the maximum which will be present in actual commercial production. We have had samples of pipe under study similar to field conditions for about three years and so far there has not been a single case where trouble occurred.

Referring to Mr. Faucett's comments on the type of deposit on the lead when subjected to steam and the solubility of the corrosion film: it is our understanding that where severe corrosion is encountered, neither a soluble or insoluble, adherent or nonadherent film will protect a lead sheath. It is necessary to use protective coverings such as rubber or synthetic plastics. At the same time, where the corrosion films are of the nonsoluble, adherent type, they are generally embedded not as uniform films but as segregated incrustations, and thus pronounced pitting takes place which hastens failure.

We agree with Mr. Faucett that the data on physical properties are within the degree of experimental error and that is why it is claimed that the properties of the treated lead are not changed. We are not trying, for example, to obtain higher tensile strength but are cleansing the lead before it is used for sheathing in order that the resulting pipe will be more uniform in its characteristics throughout its entire length than is possible with lead not so treated. We are able to control very easily the treatment of the lead and none of the difficulties anticipated by Mr. Faucett has been experienced.

We do not agree with Mr. Faucett that the microstructure of extruded pipe shown in figure 3 is not representative of present day practice as a whole. Some cable manufacturers have improved their previous practice but we have been able to examine sheaths occasionally and have found flow lines even in pipe from the vacuum press.

We wish to correct Mr. Faucett's statement that we have not investigated the vacuum press. We do not use the vacuum press but we have thoroughly investigated it and studied it in operation. We decided that it did not accomplish what we wanted, namely, uniting of the charges. The ram and cylinder operation is complicated and the melting pot, although good, does not remove sulphides and other deleterious impurities, such as allotropes of lead formed in the initial stages of oxidation. These have specific gravities close to that of lead and are dispersed through the lead.

We wish that the alkalies used in standard refining methods were effective in removing sulphur as that would save the expense of using a separate treating operation.

It is agreed that oxygen is not present in significant quantities and the paper does not make this statement. If oxygen were present, it would immediately react with molten lead to form lead oxides. It is pointed out in the paper that, after the treatment of the lead with sodium, there remains about 0.001 per cent sodium in the lead. This prevents further oxidation while the lead is in the melting pot and while being poured into the cylinder, even though it is exposed to the air.

No difficulty has been experienced in etching or taking photographs of our stabilized lead with the same etching solutions as used for nontreated lead. Rather than tarnishing more readily, the surface of the treated lead remains brighter for a much longer time.

As before stated, we use the commercial brands of lead, and, like others, did not ap-

Table III

Per Cent					
Antimony Added	Sodium Added	Antimony Retained	Sodium Retained	Heated to Deg F	Duration of Heating (Minutes)
0.07		0.07		850	30
0.07		0.035		1,200	30
0.07	0.02	0.07	0.001	850	30
0.07	0.02	0.035		1,200	30

preciate that the oxides and sulphides present were in sufficient quantities to be objectionable although actually of small magnitude.

Through our method of filling no difficulty is encountered in obtaining a completely fused area. A permanent bond, clear to the edge of the cylinder and for about four to six inches into the old charge, results from this procedure, as is shown in figure 5, and by the numerous etched slugs on exhibition in our laboratory.

References 11, 12, and 13 cited in the paper clearly show that certain oxides are to some extent soluble in molten lead. Naturally, it is obvious that it is only on solidification that segregation along boundary lines will take place.

It is well known that the presence of metallic impurities in lead will decrease the tendency to form dross. For instance, lead containing small quantities of copper, tin, or antimony will definitely form less dross for a given time and temperature than lead free from metallic impurities as reported by G. O. Hiers. Thus, if we are to accept Mr. Zickrick's statement that the lead used by D. M. Smith contained more metallic impurities than in use at present by the cable manufacturers, then the tendency to dross, especially under reduced pressure, should have been eliminated at least after the first heat and vacuum treatment.

It is true that the purer the lead the lower will be the tensile properties and the larger will be the grain size and the lower the resistance to fatigue. However, by our technique of sodium treatment, metallic impurities are not removed. The process is a stabilizing one and not a metallurgical refining process. Therefore, the tensile strength of sodium-treated lead is the same as for untreated lead while the resistance to creep is somewhat greater owing to the more uniform and better bonding of the crystals.

The tensile-strength figures given for treated and untreated lead in table I are all very similar and within five per cent, except for the electro plus 0.01 per cent lithium. Tensile tests on strips cut from lead pipes cannot be expected to check any closer than 5 per cent.

The treated electro plus 0.01 per cent lithium lead has a higher tensile strength than the untreated, probably due to the formation of a binary alloy of sodium and lithium.

Regarding figure 7, it is well known that when the creep rate of two leads is compared, the stress at which it is tested must be taken into account. Thus the creep rate of noncopper-bearing lead is much greater than that of copper-bearing lead when tested at 850 pounds per square inch, but the creep rates are equal at some lower stress.

The 500-pound-per-square-inch creep tests of figure 7 and figure 8 are not strictly comparable, one being made on strip and the other on pipe. In the pipe tests the lead is stressed in at least two directions, but in only one direction on the strip tests. The simple pipe formula was used for calculating hoop stress and not the Philadelphia Electric Company formula.

We agree with Mr. Phelps that different results may be obtained when making long-time and short-time tests. We do not consider our tests as short-time tests because, even with the pressure steps used, they have extended over periods of a month or more.

Instruments and Methods of Measuring Radio Noise

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Synopsis: This paper embodies the relevant agreed recommendations of the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA, as to the nature, essential characteristics, and performance of an instrument for the measurement of radio-noise voltages. It further gives detailed descriptions of the recommended practices for measuring radio noise directly from low- and high-voltage apparatus, for making noise measurements along overhead lines, for determining broadcast field-strength levels, and methods of collecting data for the establishment of radio-noise standards.

RADIO-NOISE effects are produced by extraneous electrical fields associated with transient conditions in an electric circuit. In order that apparatus producing these effects can be treated and described in precise terms and the most satisfactory method of radio-noise suppression employed in a given case, it is necessary that there be some means of measuring the radio-noise voltages that are significant in relation to radio reception. It is also desirable that there shall be a national understanding and agreement as to the method of measurement.

The noise voltage produced by electrical apparatus on a given system depends upon the high-frequency voltage generated, the internal impedance of the apparatus, and the character and impedance of the load. This voltage is propagated by conduction, induction, radiation, or a combination of these. All metallic materials, whether used normally for electrical systems or for other purposes, may conduct high-frequency energy.

The radio-noise effect of electrical apparatus on a receiver antenna is influenced by most of the above factors. No definite method has been developed that will permit the calculation of voltage on a receiver antenna when the noise voltage produced by electrical apparatus is known.

Through the co-operative efforts of the Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association, the measurement of radio noise has been placed on an engineering basis. In 1932 this committee adopted specifications for a radio-noise meter and methods of measurement. These were published in NELA Publication No. 32 in 1933. These specifications were revised and published in EEI Publication C9, NEMA Publication 102, and RMA Engineering Bulletin No. 13 in 1935. Due to the advances in the radio art and the increased use of the radio-frequency spectrum, it has been necessary to extend and bring up to date these specifications. All the field data in this paper were taken with a meter built according to the old specifications. However, similar data taken with an instrument according to the new specifications would not be sufficiently different to change the interpretation of the results.

The development of these specifications has resulted in the application of engineering principles to the reduction of radio noise produced by certain types of electrical apparatus. The continuation of this work shows promise of producing more beneficial results in the future.

Radio-Noise Meters

A meter for measuring radio noise should give results which are comparable with the effect of the noise as heard in the loudspeaker of a radio receiver, and at the same time should be accurate and rapid in operation.

Radio noise from different types of apparatus differs in character; some types of noise have high amplitude but are of short duration, whereas others are more nearly sinusoidal in form. Furthermore, the characteristics of the radio receiver upon which the noise impinges will have an effect on the noise characteristics, so that the wave shape of the noise pulse at the output of the receiver may

Paper 39-144, recommended by the AIEE committees on communication and power transmission and distribution, and presented at the AIEE combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939. Manuscript submitted April 13, 1939; made available for preprinting May 17, 1939; released for final publication September 13, 1939.

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differ materially from that at the input.

A noise meter designed to measure the characteristics of the noise pulse as it exists at the input to a radio receiver would be a complex and cumbersome piece of equipment because it would be required to measure noise potentials of the order of microvolts and would have to be capable of amplifying all types of pulse shapes without distortion. Such a device would not be suitable for field measurements and furthermore the results would require correlation with observations of the interfering propensities of the many types of noise.

The most practical type of noise meter is one which is essentially similar to a radio receiver, with indicating means in the output. Such a device may be made convenient to operate, portable, and reliable. The indications of noise intensity for various types of noise on this type of noise meter depend upon the design constants chosen, but it is preferable to have a simple indication such as this type of noise meter provides and then to classify types of noise-making apparatus if necessary, rather than to use a complex noise meter which does not alter the noise pulse, as in the latter case classification of noise types is replaced by correlation of pulse shapes.

Indicating Means

There are three general types of output indicators which may be used:

1. Oscilloscopes
2. Wave-form analyzers
3. Indicating meters

Oscilloscopes and wave-form analyzers are useful for theoretical investigation of noise, but do not provide ready numerical means of expressing results, and are more difficult to use than an indicating meter. Indicating meters are convenient and reliable so are to be preferred for general use.

Frequency Range

The noise meter should cover the entire radio spectrum of interest for reception, which is from approximately 150 kilocycles to at least 100 megacycles. However, the design problems for frequencies above 20 megacycles differ materially from those for frequencies below that value so that it is more practical to design two separate instruments, one for frequencies below 20 megacycles and one for frequencies above 20 megacycles. This discussion will be confined primarily to the meter for frequencies of 150 to 350 kilocycles and 540 to 20,000 kilocycles. The wide frequency range dictates the use of the superheterodyne circuit, and because the intermediate frequency thereof will probably be the RMA standard value of 455 kilocycles, there will be a range on either side of this frequency which will not be covered, namely 350 to 540 kilocycles.

Detectors and Indicating Meters

Since the noise is transmitted through the instrument at radio frequencies, detection is necessary before applying the resultant audio-frequency pulse to the indicating meter. The indicating meter may be arranged to read root-mean-square, average, or peak value of the wave. It is generally recognized that on noise pulses of short duration, meters reading average or root-mean-square do not indicate values as high as those disclosed by listening tests. A peak or quasi-peak indicating device has been found to give meter readings more nearly proportional to the auditory interference experienced. Since a peak-reading meter is desired, the meter may be in the detector circuit, thereby eliminating audio amplification. The use of a meter in the detector circuit has the further advantage that calibration of the device can be made by application of an unmodulated carrier-frequency voltage, thus eliminating the necessity of modulation

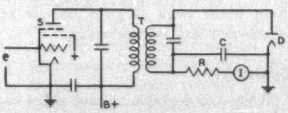


Figure 1. Detector circuit

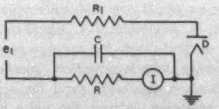


Figure 2. Equivalent detector circuit

thereon, and eliminating the necessity of determining the modulation factor.

A detector for noise measurement should meet special requirements, but with due regard for practical design limitations. A typical diode detector, which is the most satisfactory and reliable type detector, is shown in figure 1. The radio-frequency voltage, e, noise or signal voltage as the case may be, is applied by preceding amplifier circuits to the input of the final intermediate-frequency amplifier tube S. Tube S in turn impresses the voltage on diode D through the intermediate-frequency transformer T. In the diode circuit are a resistance R, a capacitor C, and the current-indicating meter I. Tube S and transformer T can be replaced by an equivalent voltage e_1 and resistance R_1 as shown in figure 2. Capacitor C is charged by e_1, through R_1 and discharges through R. The time constant on charge is then R_1C and on discharge RC.

If voltage e_1 is a suddenly applied potential, capacitor C will charge to 63 per cent $(1-1/\epsilon)$ of e_1 in time R_1C. On discharge the voltage of C will drop to 37 per cent $(1/\epsilon)$ of its initial voltage in time RC. Now if the discharge time constant RC is long in comparison with the charge time constant R_1C, the voltage of C will build up to very nearly the peak value of the applied voltage. In considering the mechanism of build-up of voltage to the peak value, it should be borne in mind that noise voltage consists of a series of impulses, the measured voltage reaching essentially the peak value after the first few impulses. In the very rare case of noise consisting of a single pulse, or pulses with a repetition time longer than the discharge time constant of the metering circuit, a value considerably less than the peak would be indicated. However, experience would tend to show that the disturbing effect of such noises on the listener is less than would be indicated by their peak amplitude.

In determining the time constants of the metering circuit, consideration must be given to meter characteristics, noise characteristics, and to circuit design limitations. An indicating meter which is too rapid in action is expensive and is difficult to read, whereas a meter with too long a time constant makes circuit design difficult. A meter with a time constant of 200 to 400 milliseconds is suitable, the time constant of the meter for this use being considered as the time required for the meter to deflect from zero to an equilibrium position upon the application of a steady current equal to about two-thirds full-scale value. This corresponds to a meter with a natural period of 0.5 to 0.7 second with a damping factor of 10 to 100 determined according to American Standards Association standard methods.

It is desirable that the time constant of the noise meter be determined by the circuit values rather than by indicating-meter constants, because the former are more readily determined and may be held more closely. By making the circuit charge time short and discharge time long in comparison with the indicating-meter time constant, this may be accomplished.

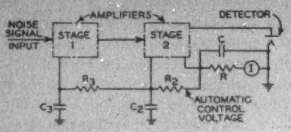


Figure 3. Logarithmic amplifier

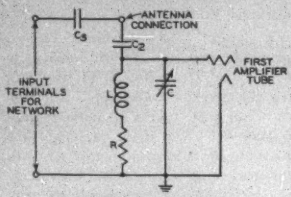


Figure 4. Input circuit

It is difficult to secure an equivalent resistance on charge (R_1 of figure 2) of less than 20,000 to 30,000 ohms with receiving-type vacuum tubes, whereas fixed resistors for discharge (R of figure 2) become difficult to determine accurately and are not stable in value above approximately 5 megohms. This, therefore, in conjunction with the indicating-meter constants determines the permissible range of values for C and for charge and discharge time constants. It should also be borne in mind that the peak voltage is given by IR so that for any value of voltage, the lower we make R, the greater I will become, thus permitting use of a less sensitive indicating meter. In some cases where it is desirable to use a relatively insensitive meter and a high value of R, a d-c amplifier may be used. From the above considerations, a charge time constant of the order of 10 milliseconds and a discharge time constant of the order of 600 milliseconds are indicated.

The following tabulation shows several possible combinations of circuit values which result in these time constants for charge and discharge.

R (Megohms)	C (Microfarads)	R_1 (Ohms)
5	0.12	83,000
4	0.15	67,000
3	0.2	50,000
2	0.3	33,000
1	0.6	17,000

If it is desired to measure the signal intensity of a broadcast-station carrier or to use the audio-frequency noise output for listening or other type of indication, the time constant RC should be of the order of 0.1 millisecond, which may be done by appropriate reduction in the value of C when such measurements are required.

Selectivity

Steep-wave-front disturbances involve a broad band of frequencies for their transmission and when transmitted through a selective amplifier undergo a change in shape. The energy content of a high amplitude pulse of short duration is unchanged by a selective amplifier, but its maximum amplitude is decreased and its duration correspondingly increased. Since this shape alteration of sharp pulses takes place in radio receivers in proportion to their selectivity, in order to correlate noise-meter indications with radio reception, it is desirable to have comparable selectivity. The over-all pass band of radio receivers, from antenna to loudspeaker, varies widely, from about 1,500 cycles in the lowest-priced receivers to 6,000 or 8,000 cycles in the case of receivers of high fidelity. Since good-quality receivers merit additional consideration, the noise meter should have somewhat greater pass band than that of the average receiver. The high-frequency end of the pass band is of prime interest, frequencies lower than 60 cycles seldom being of interest in noise studies. The noise meter should then transmit frequencies of 4,000 to 5,000 cycles, which means the selective circuits should have a band width twice as great because of double-side-band considerations.

Sensitivity

While it is desirable to have signal intensities of five to ten millivolts per meter from broadcasting stations for good reception, there are many localities where no signal over 500 microvolts per meter is available. A signal-to-noise ratio of 30 decibels for average program to average noise is generally conceded to constitute a minimum ratio for acceptable reception so that the noise meter must be capable of measuring noise voltages of the order of ten microvolts. It is seldom that noise voltages of more than 100 millivolts are of interest, which determines the upper limit of noise-meter calibration. However, such voltages should not undergo any limiting action by the noise meter, nor should such voltages cause generation of spurious responses, so the amplifiers of the noise meter should be capable of handling peak values up to about ten volts input.

Meter Scales

A scale on the indicating meter which is logarithmic in character has several advantages over a linear scale. In the first place it fulfills the psychological conditions of Weber's law and in addition makes the use of fewer attenuator taps possible, with resultant increase in simplicity of construction and use.

The logarithmic characteristic is best secured by electrical means. The deflection law of the meter itself is linear, the angular deflection of the pointer being proportional to the current through the meter.

The automatic-volume-control system as used on radio receivers provides a ready means of obtaining such a characteristic. By the use of remote-cutoff vacuum tubes in the noise-meter amplifier stages, a sufficient amount of control can be applied to each stage to obtain a

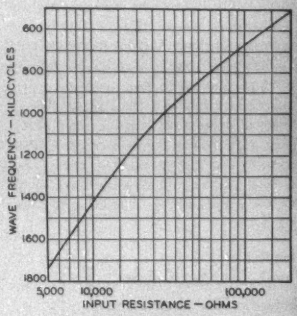


Figure 5. Noise-meter input resistance with circuit of figure 4

useful input range of about 40 decibels on each meter scale range without amplifier overload or distortion.

In figure 3 is shown the method of obtaining logarithmic indication. The direct current developed by the detector is filtered by R_3C_3 and R_4C_4 to eliminate any intermediate-frequency or noise component and is then applied to bias the amplifier stages. The time constant of the filter should be of the order of 200 milliseconds so that it will not influence the meter indication, the time constant for noise measurement being that of the detector circuit only.

The meter scale is calibrated logarithmically in microvolts or linearly in decibels above one microvolt and the value of noise input in microvolts is thus read directly on the indicating meter.

The meter scale is useful over a ratio of inputs of about 100 to 1 by virtue of the logarithmic system used, but in order to cover the entire desired range of 10 to 100,000 microvolts, multipliers of 10

and 100 should be used. These multipliers are in the form of attenuators for the noise input, and in order that none of the tubes be overloaded, must precede the first tube. The attenuator may be of the resistance type, or may be of the capacitance or mutual inductance type, any one of which can be made to have the desired attenuation independent of frequency.

Input Circuits

The input circuits should be suitable for use either with a vertical-rod antenna for measuring noise or signal field intensities or as a voltmeter. In either case the impedance of the input system should be high, so that the voltage existing on the antenna or across a standard coupling network will not be affected by connection of the noise meter. One type of input circuit which fulfills these requirements is shown in figure 4.

The antenna should be a relatively short vertical rod with an effective height of one-half to one meter which means a physical height of approximately twice that value. Such an antenna has an inherent capacitance of 10 to 20 micromicrofarads, and C_a should have the same capacitance so that the input circuit will be tuned correctly when the meter is used either with the antenna connection or as a voltmeter.

The impedance of this type input system is a pure resistance when tuned for maximum response as the LRC circuit under such condition becomes an equivalent resistance and inductance in series, the value of the inductive reactance being equal to the capacitive reactance of C_1 and C_2 in series. In order to secure a suitable high impedance, a small capacitance C_3 is placed in series with the circuit. The capacitance of C_a and C_3 in series should be of the order of three micromicrofarads. If we assume this to be three micromicrofarads and L to be 166 microhenries, and the power factor of L to be one per cent, at broadcast frequencies, the equivalent resistance of the input circuit as a function of frequency will be as shown in figure 5.

Calibration Source

The noise meter should be battery operated for field use, which means that the gain will change with battery usage as well as due to aging of tubes and effects of atmospheric humidity. In order to make the instrument readings accurate, the gain must be standardized each time the instrument is used. The gain standardization requires the incorporation of a self-contained calibrating source. The primary calibration should be performed by means of a standard signal generator but a comparison standard must also be included in the noise meter itself.

There are three possible types of calibration sources which might be used, an internal radio-frequency oscillator with a meter to indicate its output, the inherent thermal agitation noise voltage of the noise-meter input circuit, or the shot noise from a saturated diode. The latter two are simple to incorporate and depend only upon constancy of resistance of the input circuit. For an input circuit resistance of 10,000 ohms and a band width of 6,000 cycles, the thermal agitation voltage is 1 microvolt at a temperature of 20 degrees centigrade, whereas the shot noise for a current of one milliampere is 14 microvolts, under the same conditions, so is easier to apply.

The shot noise voltage is given by

$$V_s^2 = 31.8 \times 10^{-20} i R^2 F$$

at a temperature of 20 degrees centigrade where

V_s is shot noise voltage
i is current in amperes
R is input circuit parallel equivalent resistance in ohms
F is frequency pass band in cycles

The circuit of figure 6 may be used for the calibration source. LC is the input tuned circuit and R is a resistance shunted across this circuit during calibration so that the total circuit resistance will be more uniform with frequency. B is a battery of sufficient voltage so that the diode draws saturation current. R_1 is a resistor which varies the diode filament temperature until the space current as read by meter I reaches the calibration value. Meter I may be the output indicator of the noise meter switched to the position shown in figure 6 for calibrating purposes. The amplifier gain is then adjusted to standard value by variation of screen or initial bias potential.

In the design of such instruments, due consideration must also be given to shielding, image-frequency response, and intermediate-frequency response ratios, so that the noise indicated is due only to that existing at the frequency to which the meter is tuned.

Methods for the Measurement of Radio-Noise-Influence Voltage Produced by Electrical Apparatus

The term "noise-influence voltage" will be used hereafter to describe the radio-noise voltage measured at the terminals of electrical apparatus when connected to a coupling network. This term is used in order to make a definite distinction between this voltage and the radio-noise voltage that may appear at the input terminals of a radio receiver. The noise voltage that appears between the antenna and ground will hereafter be referred to as the "noise voltage."

Noise-Influence Voltage of Low-Voltage Devices

The noise voltages produced by low-voltage electrical apparatus are generally caused by the transmission of high-frequency currents along the wires or conductors connected to the apparatus. These currents are due to the electromotive forces produced by the apparatus at its terminals. As such apparatus is generally grounded or has a substantial capacity to ground, the currents will not be confined to the conductors connected to it but will in addition be propagated via ground. It is, therefore, necessary

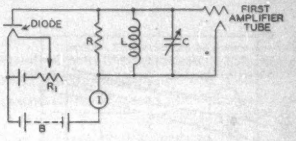


Figure 6. Calibration method

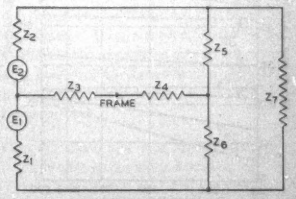


Figure 7. Equivalent circuit showing the various impedances involved when a universal motor is connected to a line

Z_1, Z_3—Impedance of field windings
Z_2—Capacity of field windings and armature to frame
Z_4—Capacity of frame to ground
Z_5, Z_6—Impedance from line to ground
Z_7—Impedance from line to line
E_1, E_2—High-frequency voltage developed at brushes

to consider the disturbing currents as consisting of two components, one corresponding to the electromotive force acting between the various conductors, hereafter referred to as the line-to-line noise-influence voltage (E_L) and the other

corresponding to the electromotive force acting between the ground as one pole and the conductors jointly as the other, this being hereafter referred to as the line-to-ground (E_g) noise-influence voltage.

Effect of Variation in Termination on the Noise-Influence Voltage

The amplitude of the noise-influence voltage produced by electrical apparatus is determined by the external terminating impedance as well as its internal impedance. This may be seen by referring to figure 7 which is a simplified circuit for the various impedances involved when a universal motor is connected to a supply line. It will be noted that the line impedance network is represented as a delta system. In service conditions, the voltage induced upon a receiver antenna is associated with the vector sum of the voltages across Z_4 and Z_4. Consequently, any network that is developed should be so designed that the line-to-ground com-

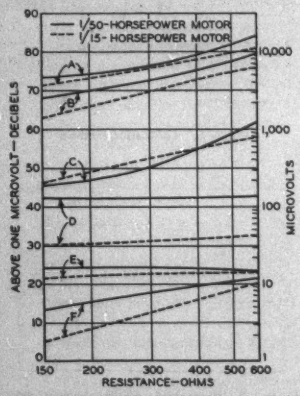


Figure 8. Noise-influence voltage from 1/50- and 1/15-horsepower universal motors with various terminating impedances

A—Line to ground, frame grounded
B—Line to line, frame grounded or ungrounded
C—Line to ground, frame ungrounded
D—Line to line, frame grounded or ungrounded—filtered
E—Line to ground, frame grounded—filtered
F—Line to ground, frame ungrounded—filtered

ponent will be taken vectorially. This can be accomplished readily by a star network as shown by figure 11.

The noise-influence voltages produced by 1/50- and 1/15-horsepower motors with terminating impedances of 600–300 and 150 ohms are shown by figure 8. It will be seen that the measured average noise-influence voltages are seven decibels higher with 600 ohms than with 300 ohms and five decibels higher with 300 ohms than 150 ohms in the following conditions:

1. Line-to-line, grounded or ungrounded (not filtered)
2. Line-to-ground, grounded and ungrounded (not filtered)
3. Line-to-ground, ungrounded (filtered)

Where filters are applied to the motors all three impedances give identical line-to-line and line-to-ground (frame grounded) voltages.

Some field tests have indicated that the variation in the impedances of supply lines in homes may vary from 10 to 2,000 ohms with an average around 150 to 300 ohms. Other investigators have measured an average impedance of 80 ohms. The supply-line impedances vary considerably from location to location and are not pure resistances but contain reactive terms. Some of the supply lines that have been measured were resonant in the broadcast band. Lines with impedances that contain reactive terms may increase or decrease the noise voltage from electrical apparatus, depending upon their phase relation with respect to the internal impedance of the apparatus. The impedance of supply lines may vary from day to day. Turning on a lamp may change the line impedance characteristics so as to cause the noise voltage from apparatus to increase or decrease a considerable amount.

Field tests indicate that the impedance of each wire to ground is different, thereby causing a high-frequency unbalanced termination for the apparatus. Laboratory tests have indicated that the minimum noise voltage from electrical apparatus will be obtained when the terminating impedances are balanced with respect to ground. A mathematical analysis of figure 7 will also show this.

This effect was determined by using a circuit as shown by figure 9 where *A*, *B*, and *C* were the terminating resistors and the other network utilized to measure the vector sum of the line-to-ground voltage. When *A*, *B*, and *C* were 200, 300, and 300 ohms respectively, providing a resultant resistance of 150 ohms between lines and between each line and ground, the line-to-ground voltage was 240 microvolts. When *B* was short-circuited, *C* made equal to 600 ohms, and *A* equal to 200 ohms, providing a line-to-line resistance of 150 ohms and 150 ohms from one line to ground, the line-to-ground voltage increased to 1,920 microvolts. This impedance unbalance resulted in a line-to-ground voltage that was three times as great as the line-to-ground voltage obtained with a balanced 600-ohm network. This test probably produced a greater unbalanced condition than will exist in practice. However, it does show the necessity of considering unbalanced systems in the field.

Field measurements on unfiltered devices also indicate that, because of the impedance unbalances of supply systems, the networks used for measuring the noise-influence factor should have impedances greater than the average line impedances measured in the field. Figure 10 shows the ratio between the noise-influence voltage produced by a motor when terminated with a 600-ohm network and as measured on various supply lines. In this figure the ordinates are the average of the voltage measurements taken

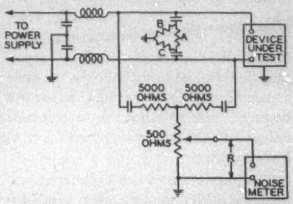


Figure 9. Circuit used to determine the effect of unbalancing the terminating impedance

at three frequencies in 20 residences. It may be seen by this curve that 50 per cent of the cases had 25 per cent or more of the voltage measured on a 600-ohm network. Twenty per cent of the cases had 60 per cent or more of the voltage measured on the 600-ohm network. If this motor had been measured on a 150-ohm network, 50 per cent of the cases would have had a voltage on their supply line that would have been 100 per cent or more of the voltage measured when using a network.

Circuits Used for the Measurement of Radio-Noise-Influence Voltage at the Terminals of Apparatus Normally Connected to Single-Phase Domestic Supply Lines

The auxiliary devices and detailed methods of measurement contained in this paper have been developed primarily for the 550–1,500-kilocycle broadcast band. It is probable, however, that

the same methods can be used for measurements at frequencies higher than this, but since the problem of measurement at these higher frequencies is now in the developmental stage, the scope of this paper, so far as detailed measurement procedure is concerned, is limited to frequencies below 1,600 kilocycles.

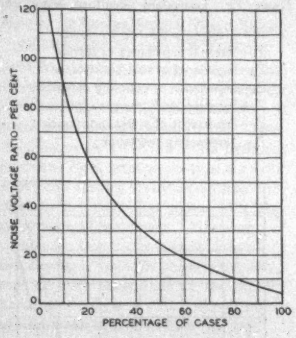


Figure 10. Per cent of noise-influence voltage existing on supply lines

The measurement of noise-influence voltage at the terminals of single-phase low-voltage apparatus such as motors, appliances, etc., is accomplished by a circuit arrangement as shown in figure 11.

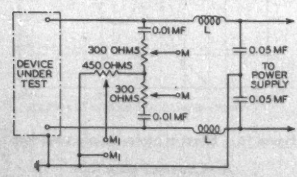


Figure 11. Circuit for the measurement of noise-influence voltage produced at the terminals of single-phase low-voltage devices

M-M—Terminals for line-to-line measurements
M_1-M_1—Terminals for line-to-ground measurements
L—Radio-frequency choke coils

Measurement of the line-to-line voltage (E_L) is made by connecting the radio-noise meter across the terminals *M-M*. This voltage may be obtained by measuring the voltage across a known portion (R) of the 600-ohm resistance between lines. This measured voltage is multiplied by $600/R$ to obtain E_L.

Measurement of the line-to-ground voltage (E_G) is made by connecting the radio-noise meter across the terminals M_1-M_1. This voltage may be obtained by measuring the voltage across a known portion (R) of the 450-ohm resistance. The measured voltage is multiplied by $600/R$ to obtain E_G.

This network is constructed with resistors that are noninductive at the radio frequencies employed in the measurements. These resistors may be of the metallized filament or carbon type commonly used in radio receivers. They should preferably be mounted with the coupling capacitors in a nonferrous metallic case. The resistance values should not differ from the specified values by more than five per cent plus or minus. Furthermore, the resistance between one line terminal and the ground terminal should not differ by more than one per cent from the resistance between the other line terminal and the ground terminal. Taps for suitable ratios can be secured by proper selection of resistor units.

It is necessary that the radio noise already existing in the supply circuit independently of the apparatus under test should not be included in the measurements and that the normal impedances existing between the supply lines and ground should not modify, in any essential respect, the characteristics of the measuring circuit. These two results are achieved by inserting in each supply lead between the measuring circuit and the terminals of the supply line a choke having a radio-frequency impedance of not less than 5,000 ohms at the frequency of the test. The chokes must be so designed that any drop in the supply voltage due to the load current of the apparatus does not cause the terminal voltage to fall below the normal rating of the apparatus.

Method of Making Measurements

The frame of the apparatus is normally grounded.

The final reading is the mean of the values measured during a period of not less than ten seconds.

In the case of apparatus having noise-influence voltages of the nature of impulses with long intervals between them, the reading is the mean of the values of ten impulses.

The network should be connected to the supply circuit by a twisted pair of leads 24 inches long and to the noise meter by leads not exceeding 4 inches.

It has been the experience to date that it is necessary to ground the device under test if comparable results in various locations are to be obtained. However, for apparatus that is normally ungrounded in service the grounding of the apparatus may increase considerably its apparent ability to produce noise. Because of the lack of information on this subject it is desirable to include in this paper the precautions that must be taken when measuring ungrounded apparatus.

In order that the capacitance to ground of apparatus tested ungrounded shall be

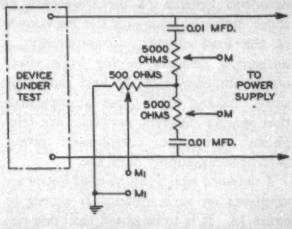


Figure 12. Circuit for the measurement of noise-influence voltage on equipment in the field

M-M—Terminals for line-to-line measurements
M_1-M_1—Terminals for line-to-ground measurements

standardized for the purpose of measurement, the apparatus under test should be placed 15 inches above the metallic floor of the test room in an insulated position. The distance to the walls of the room should not be less than 15 inches. The radio-noise meter, networks, and the person in charge of the test should be at a distance greater than 15 inches from the apparatus. If a shielded room is not available, the apparatus should be placed at a height of 15 inches over a grounded metal plate which is not less than seven by seven feet.

Circuit Used for the Measurement of Noise-Influence Voltage at the Terminals of Low-Voltage Three-Phase Equipment

A network similar to that used on single-phase apparatus may be used for three-phase systems. The network consists of three 300-ohm resistors connected in Y with a 500-ohm resistor connected from the neutral to ground. This arrangement provides a network with 600 ohms between phases, and 600 ohms between ground and all phases in parallel. The line-to-line voltage (E_L) between any two phases may be obtained by measuring the voltage across a known portion (R) of the 600-ohm resistance between the lines. This measured voltage is multiplied by $600/R$ to obtain E_L.

The line-to-ground voltage (E_G) may be obtained by measuring the voltage across a known portion (R) of the 500-

ohm resistance, and multiplying the measured voltage by $600/R$ to obtain E_0.

Measurement of Radio-Noise-Influence Voltage on Equipment in Normal Service

In normal service the noise-influence voltage of apparatus cannot be measured accurately by the networks previously described because of the possibility of these networks changing the impedance of the load circuit. Consequently, a measuring network having little effect on the impedance of the load should be used. Among those types of apparatus that require different networks are telephone equipment, complicated power switchboards, supply lines, etc.

A network which can be used for measurements on such systems is shown in figure 12. It is to be noted that this circuit is fundamentally the same as the network used for single-phase measurements, differing only in the change of circuit constants and omission of filter chokes.

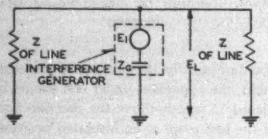


Figure 13. Schematic circuit of a typical high-voltage interference generator

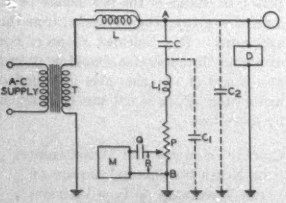


Figure 14. Circuit for the measurement of the noise-influence voltage produced by high-voltage devices

T—Testing transformer
L—Radio-frequency choke, not less than 20,000 ohms at frequency at which measurement is made
M—Radio-noise meter
C—Coupling capacitor, not less than 0.0025 microfarad
G—Dummy antenna
D—Device under test
P—Potentiometer or tapped resistor, 600 ohms resistance, nonreactive
L_1—Inductance between capacitor and potentiometer, ten microhenries, approximately
C_1—Stray capacitance on potentiometer side, not over 50 micromicrofarads
C_2—Stray capacitance on bus side, not over 60 micromicrofarads

By connecting the radio-noise meter to terminals *M-M*, the voltage across a known portion (R) of the 10,000-ohm resistance between lines can be measured. This measured voltage when multiplied by the conversion factor $10,000/R$ gives the noise-influence voltage between lines.

The line-to-ground noise-influence voltage is obtained by connecting the radio-noise meter at points M_1-M_1 across a known portion (R) of the 500-ohm resistor. When the lines are considered jointly, their resistance to ground is 3,000 ohms; thus the conversion factor for the line-to-ground measurement is $3,000/R$.

Radio-Noise-Influence Voltage of High-Voltage Apparatus

The radio-noise voltage produced by high-voltage apparatus is influenced by the same means as the low-voltage devices. It is propagated in the same fashion and the difficulties of determining the radio-noise effect on receivers are as great if not greater than that from low-voltage devices. Consequently, it is necessary, as it is on the low voltage, to measure the noise-influence voltage from this type of apparatus on a standard network.

The noise-influence voltage produced by high-voltage equipment depends upon the internal impedance of the apparatus and the line impedance. An interference generator and its load impedance is shown by figure 13. All high-voltage apparatus generally has an impedance to ground at broadcast frequencies that is larger than the line impedance to ground. Because of this condition, the line impedance affects the transmission line-to-ground voltage E_0. For open-wire lines the impedance Z is between 400 and 600 ohms unless the line is shorter than 10 or 12 wave lengths.

A circuit similar to figure 14 has been used by a number of manufacturers to determine the noise-influence voltage of line apparatus, such as insulators, bushings, and fuse cutouts.

Because of the effect of the distributed capacitances of the high-voltage conductor and coupling capacitor it is necessary to limit these distributed capacitances to the values shown in figure 14 in order that the error be kept under ten per cent at 1,000 kilocycles, where the majority of the measurements are made.

A simplified circuit to show the effect of these distributed capacitances on the voltage measured is shown by figure 15. It is the same as figure 14 except the impedance of the choke coil and transformer has been neglected. If the choke coil in series with the transformer has the impedance specified, this part of the system can be neglected.

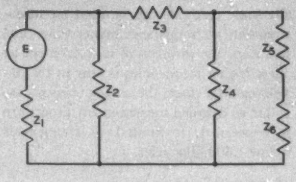


Figure 15. Equivalent circuit of figure 14

E—Voltage produced by device
Z_1—Internal impedance of device
Z_2—Impedance of stray capacitance C_2
Z_3—Impedance of coupling capacitor
Z_4—Impedance ofs tray capacitance C_1
Z_5—Impedance of series inductance
Z_6—Terminating resistance

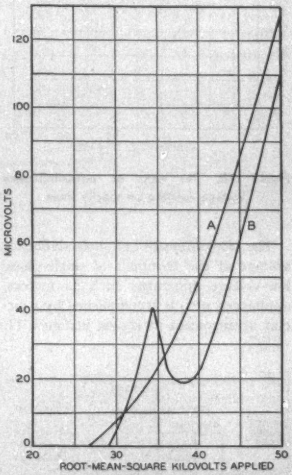


Figure 16. Effect of power-supply wave form

A—Corrected wave form
B—Distorted wave form

The voltage appearing across the resistance R figure 14 (Z_6 figure 15) is:

$$E_{Z_6} = E \frac{Z_5 Z_{11} Z_6}{Z_{11} Z_{22} Z_{33} - Z_{11} Z_4^2 - Z_{33} Z_3^2}$$

where:

$Z_{11} = Z_1 + Z_3$

$Z_{22} = Z_2 + Z_3 + Z_4$

$Z_{33} = Z_4 + Z_5 + Z_6$

From the foregoing, it will be noted that stray capacitances will introduce

errors, which must be given consideration in the design of a circuit such as shown by figure 14. If it is assumed that the voltage that would be measured with a pure resistance of 600 ohms across the device is E_R, then the error in per cent introduced by the system as shown by figure 14 is $\frac{E_R - E_{E_3}}{E_R} 100$.

Effect of Power-Supply Wave Form on the Noise-Influence Voltage

Tests in the laboratory have shown that supplying a distorted 60-cycle voltage wave to the testing transformer will produce erroneous measurements. Curve *A* of figure 16 shows the noise influence produced by a treated pin-type insulator when the testing transformer was supplied by a system that contained a high percentage of harmonics. The source of voltage for this test was such as to result in a change in both the phase relationship and per cent magnitude of the various harmonic components for various values of root-mean-square voltage readings.

Correcting curve *A* to agree with the measured crest voltage readings did not materially improve the appearance of this curve.

The testing transformer was then supplied from a motor generator set and the curve *B* as shown by figure 16 was obtained.

Field Applications

In the preceding paragraphs radio-noise meters and methods of measurement have been described in detail. With the instruments available, and with the development of a suitable measuring technique, definite progress can be made by those engaged in the investigation and mitigation of noise phenomena.

Power companies and other agencies which have used noise-measuring equipment in the field have found it to be valuable in a number of ways, some of which are enumerated as follows:

1. Investigation and analysis of complicated noise problems on transmission and distribution systems.

2. Quantitative determination of noise characteristics of electrical apparatus and appliances for the purpose of determining their suitability from a noise standpoint.

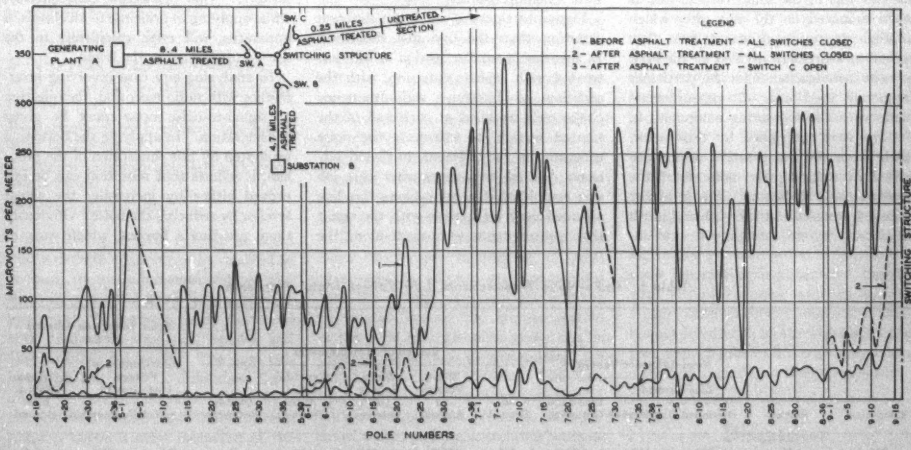
3. Analyses of situations where special devices have been applied for mitigating noise effects.

4. Accumulation of data for establishing acceptable noise levels. Examples of the foregoing applications are given in the following paragraphs:

Measurement of Noise Along Transmission Lines

Figures 17 and 18 show, in graphical form, measurements made along 66-kv pin-type transmission lines where asphalt emulsion was applied to the heads of the insulators so as to close all voids between the surface of the insulator and the energized conductor and tie wires. Figure 17 covers a situation where measurements were made over a 5-mile section of the line before and after the asphalt application. A total of approximately 13 miles of line was treated between the generating station marked *A*, and the substation marked *B*. At a point 8.4 miles from the generating station there is a switching structure from which point a tap line extends for approximately 20 miles to another generating station. Except for approximately one-quarter of a mile from the tap structure, this line was not treated with asphalt at the time the measurements were made.

Figure 17. Noise measurements along a transmission line—case I



The explanation of the higher noise level in the sixth to ninth miles lies in the fact that this particular pole line carries both 66- and 11-kv circuits arranged in vertical configuration with the 66-kv circuit occupying one side of the pole and the 11-kv circuit the other side. Measurements were taken with the noise meter placed in a car with the antenna rod mounted on the side window. As a result, the 11-kv circuit was nearest the car up to pole 6-27 and probably shielded the higher-voltage circuit to some extent, while beyond this point the conditions were reversed. In making the measurements the car was always headed in a direction such that the rod would be on the side toward the pole line. Measurements were taken at each pole at an approximate distance of 20 feet transverse to the center of the line, and care was exercised to maintain this separation at the various pole locations.

Since the installation of the noise meter in the car would be expected to affect the measurements as compared to operating the noise meter with a standard rod as a unit on the ground, an antenna

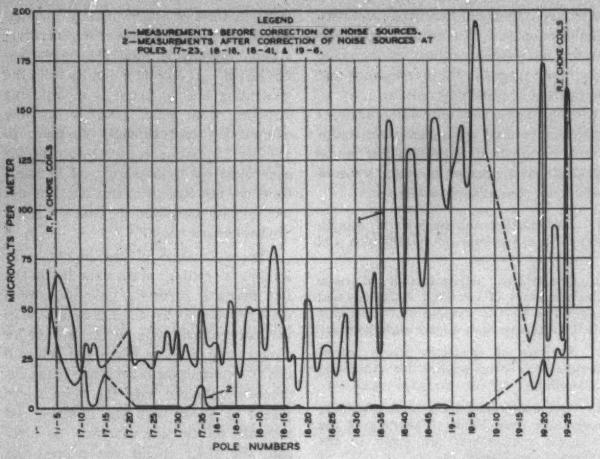

LEGEND
1—MEASUREMENTS BEFORE CORRECTION OF NOISE SOURCES.
2—MEASUREMENTS AFTER CORRECTION OF NOISE SOURCES AT POLES 17-23, 18-16, 18-41, & 19-6.
R.F. CHOKE COILS
R.F. CHOKE COILS
MICROVOLTS PER METER
POLE NUMBERS

Figure 18. Noise measurements along a transmission line—case II

factor was secured in the following manner: A pole location was selected and a measurement made with the equipment installed in the car. A mark was placed on the road directly under the rod antenna, after which the instrument was removed and the car run ahead approximately 50 feet. The instrument was then placed on the ground in a position so that the rod was in the same vertical line as when mounted on the car, after which another measurement was taken. The second measurement divided by the first, gave an antenna factor for the particular frequency used and all measurements made with the measuring equipment in the car were multiplied by this factor. Aside from the quantitative results obtained in reducing the noise level the measurements indicated that a higher noise level existed in the eighth and ninth miles and beyond, probably due to inadequate asphalt coatings, and that the closing of switch *C* on the untreated tap line, raised the noise level all along the asphalted section, thus showing the results of noise propagation along the line from a distant source.

Figure 18 shows a somewhat different situation than the one just described. In this case a smaller section of line was treated with asphalt emulsion, with the addition of line-type radio-frequency choke coils installed at each end of the treated section, to attenuate the noise generated in the adjacent untreated sections. About two years after this job was completed, the noise along this line attained very high levels with the result that measurements were made along the line as shown on curve 1. These measurements indicated a source of noise at pole 19-6 with less severe disturbances originating at other points. Due consideration, however, had to be given to the possibility of reflections from the choke coils. It developed that an insulator at pole 19-6 was found to have cracks in two of the shells which gave rise to severe noise. Incidental cases were found also at poles 17-23, 18-16, and 18-41. The correction of these conditions resulted in curve 2, which indicates a very low noise level for this type of line. In making these measurements the same precautions were taken with respect to lateral distance from the line and the determination of an antenna factor as outlined in the discussion of figure 17.

Measurements of Low-Voltage Appliances

In the measurement of radio noise produced by low-voltage electrical appliances, it is desirable to utilize the information in such a way that it will be possible to rate these devices according to their radio-noise effects when operated in a home or place of business. This feature applies also to noise levels of high-voltage equipment and their relation to reception in the home, but the data on this phase of the subject, at present, are somewhat meager. This discussion, consequently, while applying in principle to all classes of apparatus, will refer specifically to the use of appliances in the home.

In analyzing any case involving interference with radio reception, the question of signal-to-noise ratio must be given consideration. In applying the reasoning prompted by this conception of the problem, it follows that reception can be improved either by increasing the signal level or by reducing the noise. Obviously there are limits beyond which each of

Table I. Radio-Noise Measurements, Low-Voltage Motor Appliance

Kilocycles	Station	Noise-Influence Voltage* Line-Ground Grounded	Line-Ground Ungrounded	Line-Line Grounded	Residence Measurements Line-Ground†	Noise Voltage on Antenna	Signal Voltage on Antenna	Signal-to-Noise Ratio (Decibels)	Quality Reception	Noise Voltage on Antenna (Per Cent) Noise-Influence Voltage Line-Ground Grounded	Ungrounded	House Wiring, Line-Ground
610	*M*	1,200	160	208	585	107	396	11.4	*E*	8.9	66.6	18.3
660	*N*	1,280	170	188	612	97	140	3.0	*F*	7.6	58.2	15.8
710	*O*	1,310	154	166	610	79	860	20.8	*C*	6.0	42.9	12.7
760	*P*	1,200	207	145	370	30	1,240	32.3	*A*	2.5	14.5	8.1
830	*Q*	1,120	223	123	153	13	290	27.0	*B*	1.2	5.8	8.5
860	*R*	1,120	220	117	125	10	350	30.8	*A*	0.9	4.6	8.0
1,020	*S*	1,270	240	84	93	6	352	36.2	*A*	0.5	2.5	6.4
1,170	*T*	1,370	305	84	40	9	435	34.2	*A*	0.7	3.0	22.5
1,200	*U*	1,380	318	85	25	9	198	27.4	*B*	0.7	2.8	36.0
1,440	*V*	1,500	255	130			12,300		*A*			
Average		1,275	228	133	290	40				3.1	17.5	13.8

* In accordance with figure 11. † In accordance with figure 12.

these factors cannot go, these being dictated by geographical location, local conditions, the status of the art, and other considerations. While opinions differ to some extent, a number of measurements have indicated that where the signal-to-noise ratio is 30 decibels or greater, satisfactory reception is obtained. With decreasing values of signal-to-noise ratio, reception becomes increasingly unsatisfactory, finally reaching a point where all program reception is impossible when the signal-to-noise ratio is zero decibels or lower.

Table I shows a tabulation of a number of measurements made under various conditions on a motor-driven electrical appliance. The data include measurements made from line to ground (E_g) and from line to line (E_L) in accordance with the circuits shown in figures 11 and 12. All measurements of noise in the residence were made at frequencies adjacent to the broadcast-station channels, the noise at the latter frequencies being obtained by interpolation. Other measurements include the noise voltage from the customer's house wiring to ground, noise on the customer's antenna, signal on the antenna, signal-to-noise ratio in decibels, and quality of reception. The latter item is intended to indicate the reaction of the listener to various signal-to-noise ratios, and it has been found convenient to express these aural effects as follows:

A—Entirely satisfactory

B—Very good, background unobtrusive

C—Fairly satisfactory, background plainly evident

D—Background very evident, but speech easily understood

E—Speech understandable only with severe concentration

F—Speech unintelligible

By referring to table I it will be noted that a definite relation can be established between the noise-influence voltage and the results in a residence for a particular appliance. It has been found that even with the same appliance, results will vary in other residences. The data collected by the Joint Co-ordination Committee on Radio Reception of the EEI, NEMA, and RMA show that the relationship between noise measured at the factory and on the customer's antenna varies over a very wide range. This is due to such factors as the coupling between the antenna and supply system, the electrical characteristics of the house wiring system, the susceptibility of the radio receiver to noise pickup by means other than the antenna connection, and finally, the field intensity of the radio station being received. Through the accumulation and analysis of a considerable amount of data, eventually it will be possible to determine generally acceptable noise-influence voltages for appliances and other electrical apparatus. In making a study of this character it must be recognized that it is not economically feasible, and in many cases practically impossible, to select limiting noise-influence voltages which will satisfy all conditions and locations. As a result, limits that may be acceptable generally will have to be recognized as taking care of a certain percentage of cases rather than all cases.

Table II. Measurements of Signal and Noise Voltage on Antenna Systems

Kilocycles	Station	Signal		Noise		Signal-to-Noise Ratio (Decibels)		Improvement, Noise Reducing Over Conventional
		Conventional	Noise Reducing	Conventional	Noise Reducing	Conventional	Noise Reducing	
610	*M*	336	450	35	15.5	19.5	29.1	9.6
660	*N*	310	143	43	12	17.1	21.5	3.4
710	*O*	930	695	51	9.5	26.1	37.1	11.0
760	*P*	1,790	1,230	62	8	29.2	43.5	14.3
830	*Q*	530	570	80	7	15.5	38.0	12.5
860	*R*	450	336	106	8	12.5	32.1	19.6
1020	*S*	470	2,400	90	59.5	14.1	32.0	17.9
1170	*T*	560	1,570	102	33.5	14.9	33.5	18.6
1440	*V*	260	120	126	34.5	6.0	11.0	5.0

Measurements on Antenna Systems

In the foregoing paragraphs, reference has been made to the signal-to-noise ratio and to the coupling between the antenna and house wiring system. One method of increasing the signal-to-noise ratio is by reducing this coupling by means of a noise-reducing antenna system of suitable design and proper installation. Quantitative data to compare one antenna arrangement with another may be obtained by measuring both signal and noise separately on the two antenna systems and determining the signal-to-noise ratios for each antenna arrangement. Since the proper functioning of most noise-reducing antenna systems requires that the pickup section of the antenna be located beyond the intense portion of the noise field, the noise meter can be used to advantage in determining the best location for the antenna. This may be accomplished by making a survey at various points on the premises, using the noise meter and its associated antenna rod. The final results can then be checked after the antenna is installed.

An example of the data which may be secured and the results which can be obtained, is shown in table II. In this installation, the conventional antenna was an inverted L type with a 60-foot flat top and a lead-in located 40 feet from the overhead line carrying the disturbance. The noise-reducing antenna consisted of a vertical wire 37 feet long located 100 feet from the overhead line carrying the disturbance. A coupling transformer was mounted near the ground level at the lower end of the vertical antenna with a 12-inch lead to a ground pipe. From this point a twisted-pair transmission line, laid on the ground for the test, ran to the radio set in the house where another coupling transformer was installed directly at the antenna and ground terminals of the set. The conventional antenna was removed during the period of making measurements on the noise-reducing antenna. As in the case of table I, noise measurements were made at other frequencies and interpolated for the broadcast channels.

It will be noted that the signal-to-noise ratio was increased in varying degrees from 3.4 to 19.6 decibels when using the noise-reducing antenna and that on the basis of approximately 30 decibels signal-to-noise ratio, seven out of the nine stations involved were received satisfactorily with the noise-reducing antenna, while only one could be placed in that category with the conventional antenna arrangement. These data are given to indicate the application of the noise meter to a given situation rather than to show the maximum attainment possible with a noise-reducing antenna system. Under more favorable conditions with respect to antenna location and other factors, a much greater increase in signal-to-noise ratio would be a likely possibility.

Discussion

J. J. Smith (General Electric Company, Schenectady, N. Y.): The specifications for an instrument for measuring radio noise and the description of the methods of measurement given by the authors in this paper should be of considerable help to those who have to study the problem of radio interference. It is hoped that this work done under the Joint Co-ordination Committee on Radio Reception of EEI, NEMA,

and RMA will tend to produce a uniformity in the methods used by different workers and encourage measurements along the standard procedure.

In many cases of investigation of complaints of radio interference due to power equipment the only type of measurement made is to listen with a radio set. The data thus obtained, however, are not of great assistance since they tell only the relative value of the interference and the radio signal and do not give the actual value of either.

The signal field strength available for radio reception varies considerably from place to place. Thus, as far as radio reception is concerned, in a locality where the field strength is of the order of thousands of microvolts a given piece of power equipment might be used without affecting radio reception. However, when the same piece of equipment is used in a locality where the field strength of the radio signal is of the order of a few microvolts it might make reception difficult. Thus it is evident that the field strength at the point of reception is an important part of the radio-interference problem, and it is only by having a definite measure of its magnitude and also a knowledge of the magnitude of the noise-influence voltage produced by the device that the best solution can be obtained.

Another advantage of this new meter is that it is expected it will be available at a lower cost than the meters previously used. This should result in its being more widely used and thus assist in obtaining data on both the signal strengths at the point of reception and the noise-influence voltage of the electrical apparatus in the same location together with the resulting radio reception.

Similar work on studies of the problem of radio interference has been going on in Europe and a committee (CISPR) of the International Electrotechnical Commission has developed standards for a radio-noise meter quite similar to the one described in this paper. However, there are certain differences and I should like to ask the authors what these differences are and the reasons why it did not appear desirable to make the two meters the same.

Charles M. Burrill (nonmember; RCA Manufacturing Company, Inc., Camden, N. J.): The "quality of reception" ratings listed in table I are based on a subjective scale of values devised by the writer in 1934 for use in an unpublished research on broadcast reception at ultrahigh frequencies. This scale has been found useful within the RCA organization in a number of radio-noise and interference investigations. However, the figures in table I are the first to be published comparing ratings on this subjective scale with signal-to-noise ratios determined objectively with a radio-noise meter.

In 1936 we made a few tests to correlate the readings of a quasi-peak noise meter with our "quality of reception" ratings. The results of these tests were communicated to the Joint Co-ordination Committee on Radio Reception of RMA, NEMA, and EEI, but it was not possible to make at that time a sufficient number of the time-consuming listening tests to warrant the publication of definite conclusions. It is gratifying to note the agreement between our figures and those given in table I, despite the fact that different noise meters and different noises were involved.

We found average quality ratings corresponding to the signal-to-noise ratios given in the following table:

Signal-to-noise ratio (decibels)	+28	+8	+3	
Quality	*B*	*B*	*B*	
Signal-to-noise ratio (decibels)	−10	−20	−34	−47
Quality	*C*	*C*	*D*	*E*

All but the first three ratings in table I are entirely consistent with the above values. The first three ratings correspond to considerably poorer quality of reception than would be expected from our data. I believe the explanation of this is, that we used a noise of a more impulsive nature than the noise of an average commutator motor, and that our noise meter may have given to brief high peaks of noise relatively more weight than the instrument used in obtaining the data of table I.

The above partial agreement and partial disagreement, and the necessity for explanations are typical of experience when quantitative studies of interference are attempted. They illustrate why standardization of method is the greatest need in this field. The work reported in the present paper is a splendid and important contribution toward filling this need.

Automatic-Gain-Control Time Constants

In the radio-noise meter described in the paper, in which a logarithmic scale is obtained by "automatic gain control" action, the function of the indicating meter is two-fold; first, to measure a change in output, and second, to measure a change in gain which is produced by the change in output through feedback. The input corresponding to a given indication depends on both of these. If now the time constants determining the transient response of the gain-changing circuit are not the same as those determining the transient response of the indicating meter, the actual response of the instrument to noise will be a complicated function of *both* sets of time constants.

For example, if in figure 3 of the paper the time constants R_3C_2 and R_3C_4 are made 200 milliseconds as suggested in the paper, and if the charging time of C is ten milliseconds, then the response to a single isolated noise peak will be substantially as though the automatic-gain-control circuit did not exist, for C will be charged before the gain control has time to act. If this is the performance desired, then at least the time constants of the automatic-gain-control circuits should be as carefully standardized as those determining the indicating-meter action. It should be mentioned, however, that with a slow automatic-gain-control circuit there is serious danger of overloading the intermediate-frequency amplifier on impulsive noise peaks.

I believe that the time constants of the automatic-gain-control circuits should be made the same as those determining the response of the indicating meter, so that the instrument will have a truly logarithmic scale for both impulsive and sustained noises. This is accomplished by making the time constants R_3C_2 and R_4C_3 small compared with the charging time constant of C, or ten milliseconds. Some tests have indicated that this is a practical possibility.

Internal Calibrating Source

There is another possible internal calibrating source not mentioned in the paper, which I believe has received too scant consideration. In fact such a source, a relaxation oscillator, was used in a commercial radio-noise meter built in accordance with the 1932 specifications of the Joint Co-ordination Committee ("Radio Noise Meter and its Application," C. R. Barhydt, *General Electric Review*, volume 36, 1933, page 201). The method of calibration there used may not have been very satisfactory. However, I believe that the relaxation oscillator, properly designed, will be found at least as satisfactory as the shot-noise generator, and perhaps preferable to it.

There is an advantage, not mentioned in the paper, in using for a comparison standard of calibration a typical noise wave form rather than a sine wave. By so doing, changes in selectivity of the instrument are compensated for, exactly for noise wave forms of the type used, partially for other wave forms. The compensation cannot be obtained exactly for all forms of noise, because at one extreme, the peak value with noise pulses which completely overlap is proportional to the square root of the band width, whereas at the other extreme, the peak value with nonoverlapping noise pulses is directly proportional to the band width ("A Study of the Characteristics of Noise," V. D. Landon, IRE *Proceedings*, volume 24, 1936, page 1514).

Shot noise has a wave form at the one extreme, corresponding to complete overlapping of the noise pulses in the receiver, whereas a relaxation oscillator with a low repetition frequency produces a noise wave form at the other extreme, that of no overlapping. By increasing its repetition frequency the relaxation oscillator may be made to give an intermediate type of wave form, if desired.

In a large number of cases, actual noise wave forms consist of pulses repeated at twice the commercial power-line frequency (120 cycles per second), a rate too slow to cause overlapping in most receivers. Thus, a noise wave form with a repetition frequency of 120 cycles per second such as can be obtained with a relaxation oscillator, would seem more typical of radio noise than hiss such as shot noise, and therefore preferable for use in calibration.

The shot noise of a tube is very small, so that a radio-noise meter must be very sensitive if shot noise is to be used for its calibration without additional complications. This may prove a rather severe limitation to the use of shot noise for calibration, particularly for low-priced instruments.

The shot noise generated by a saturated tungsten-filament diode may be determined very accurately by measuring the average space current, although generally a correction for the finite internal resistance of the diode must be applied unless the external resistance is low. Unfortunately, a tungsten-filament tube cannot be operated from

batteries suitable for a portable instrument. Thoriated-tungsten or oxide-coated-filament tubes, which must be used instead, are much more uncertain as to saturation and noise. It seems doubtful to me whether the shot noise from such a tube can be determined any more reliably by measuring its space current than the noise generated by a properly designed relaxation oscillator can be determined by measuring its supply voltage.

The International Special Committee on Radio Interference (CISPR), working in Europe, has been investigating the design of a standard radio noise generator, and a paper describing some of their results with a relaxation oscillator used for this purpose has recently been published ("Étude et Applications d'un Générateur Stable de Tensions Perturbatrices Radiophoniques. Perturbateur Type," G. Coffin and G. Marchal, *L'Onde Électrique*, volume 17, number 204, December 1938, pages 562–74).

J. L. Clarke (Bell Telephone Company of Canada, Montreal, Que.): The authors have not mentioned whether any means have been provided in their measuring set to make the noise field audible. It has been our experience when measuring noise including several discrete and readily identifiable sounds that it is very helpful to be able to sort out the observations when one or another of the more prominent sounds is present. We have found that the addition of an audio stage and loudspeaker to the measuring set is very helpful in this connection.

W. F. Grimes (Radio Interference Engineering Bureau, Inc., Los Angeles, Calif.): The paper by C. V. Aggers and his associates presents a very complete description of instruments and methods of measurement available for the laboratory study of radio noise. Some results of comparative laboratory and field tests are also given.

It appears that the radio and electrical industries are confronted with two general problems involving the reduction of radio noise. First, the manufacturer of electrical apparatus, as is shown by the paper, has recognized the necessity for the development of radio-noise-free products. Much work has been done to devise methods which permit reproduction of laboratory results in the measurement of radio-noise-influence voltages. Second, as pointed out in the paper, measurements now made in the laboratory cannot be satisfactorily reproduced in the field due to the electrical constants of supply circuits and other such factors.

The routine investigation of radio noise in the field is in existence today on a very limited basis. So far as is known, little or no quantitative field work is being done. Funds which have been made available for field investigations, with few exceptions, have been appropriated for the immediate benefit of broadcast and electric-utility customers. This has meant the establishing of a service free to the radio listener through which improvement in radio-receiving conditions could be accomplished.

In conclusion, it would seem that closer co-operation is necessary between the manufacturers and the field agencies serving the radio listener.

When instruments and methods of measurement are devised which will permit the interpretation of laboratory results in terms of expected radio-listener satisfaction, apparatus will be produced and purchased for the direct improvement of radio reception.

W. N. Goodwin, Jr. (Weston Electrical Instrument Corporation, Newark, N. J.): In the paper reference is made, somewhat briefly, to the characteristics of the indicating instrument. It is thought that a more complete discussion of these characteristics and why the particular constants were adopted might possibly be of general interest.

In noise measurements and also in indicating sound volume, such as broadcasting-program material, the indicating-instrument pointer is continuously fluctuating, and measurements are made by estimating averages of the pointer indication, or by noting peak readings.

In view of this condition, the first question considered by the committee was whether the instrument should be overdamped, critically damped, or underdamped.

This was studied by computing the deflection-time characteristics for specific cases of the three types of motions, from the following equations of motion. These were developed and the interesting properties of the quantity n discovered by the present writer in the early years of his career as an instrument engineer.

$$\frac{\theta}{\phi} = 1 - \frac{\epsilon^{-\frac{2\pi n t}{T_0}}}{\sqrt{n^2-1}} \sinh\left[\frac{2\pi t}{T_0}\sqrt{n^2-1} + \sinh^{-1}\sqrt{n^2-1}\right] \quad (1)$$

$$\frac{\theta}{\phi} = 1 - \left[\frac{2\pi t}{T_0}+1\right]\epsilon^{-\frac{2\pi t}{T_0}} \quad (2)$$

$$\frac{\theta}{\phi} = 1 - \frac{\epsilon^{-\frac{2\pi n t}{T_0}}}{\sqrt{1-n^2}} \sin\left[\frac{2\pi t}{T_0}\sqrt{1-n^2} + \sin^{-1}\sqrt{1-n^2}\right] \quad (3)$$

where θ = deflection at any time t, resulting from the application of a constant electromotive force to the instrument circuit, which will produce a final deflection of an angle ϕ; T_0 is the undamped period of the instrument; and n the ratio of the actual to the critical damping coefficients, which the writer has designated "specific damping coefficient."

Equation 1 applies to the aperiodic or overdamped condition, equation 2 to the critically aperiodic condition, and equation 3 to the periodic, or underdamped condition.

Equation 1 may be considered the general equation from which equations 2 and 3 may be derived by making $n = 1$ or $n < 1$ respectively. When this substitution is made in equation 2 it becomes indeterminate and is evaluated in the usual manner by differentiation. Equation 3 becomes imaginary and is transformed by the relations, $\sinh^{-1} j\alpha = j \sin^{-1}\alpha$ and $\sinh jx = j \sin x$.

The three curves derived from the equations are shown in figure 1 of this discussion. Curve 1 shows the overdamped condition where the specific damping coefficient $n = 1.5$, curve 2 shows the critically damped condition where $n = 1$, and curve 3 the underdamped condition where $n = 0.825$, and the damping factor is 100, resulting in an overswing of one per cent.

The curves were computed upon the basis that the deflections of corresponding instruments reached to within one per cent of their steady-state deflection in the same time.

It will be noted that the velocity of the slightly underdamped instrument is much more uniform from zero to full-scale deflection than for the other two conditions.

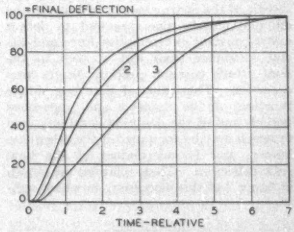


Figure 1

In the latter, the velocity is high in the lower part of the scale and diminishes rapidly in the upper part.

It is quite evident that an instrument, having a movable system giving a uniform velocity throughout its motion for a given current, would result in more correct estimates of averages and peaks than one varying in velocity. This has been proved by actual experience for a number of years in instruments for similar purposes, namely, for volume control in broadcasting. Furthermore, it results in far less eye fatigue to the reader.

For these reasons the committee adopted the slightly underdamped instrument for the noise meter.

The next question considered was that of speed of response. If the pointer action is too rapid, the eye cannot follow it; and if too slow it does not adequately follow the fluctuations in the current and gives erroneous indications. By actual tests it was found that an instrument having an undamped period of not less than 0.5 and not greater than 0.7 second, slightly underdamped, gave very satisfactory results, especially when connected into the noise-meter circuit which itself has definite time constants.

The committee thought it desirable, in order to keep the cost of the instrument within reasonable limits, to permit considerable tolerance in its constants, and for this reason specified that the undamped period may be from 0.5 to 0.7 second, and its damping factor from 10 to 100. Consideration was given to the question as to the best method of specifying response time based upon the constants just referred to. An instrument having moment of inertia, damping, and spring control does not have

a time constant similar to that possessed by a resistance-capacity circuit, or to a body heated at a constant rate, namely, the time which will reduce the exponent of ϵ in the exponential function to unity, equivalent to the time required for the quantity to reach about 63 per cent of its final value. The reason for this is that the deflection of the instrument is not only an exponential function with time but also a trigonometric or hyperbolic function, as shown in the equations given above. It would be possible, of course, to assume the time constant to be the time required to produce 63.2 per cent of final deflection as in the heat and electrical problems, but as it has no fundamental basis as it has in the latter cases, it has no especial virtue.

The time quantity which seemed to be the most practical for specifying the characteristic of the instrument, in addition to the damping, is the time required to deflect under constant electromotive force and circuit resistance from rest at zero to the final steady-current position on its first excursion. This value of time is a simple function of the damped and undamped periods and of the damping constants, any of which may be computed if the others are known, and is independent of the final scale deflection. These relations are shown in figure 2 of this discussion, in which ordi-

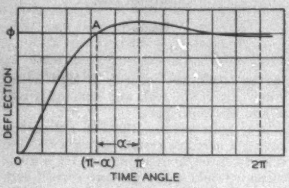


Figure 2

nates are angles of deflection, and abscissas are angles proportional to time; 2π being the angle for a complete period; and π for the half period. The angle ϕ is the steady deflection and the motion is represented by the line OA. The angle α is the phase angle of the system, equal to $\sin^{-1}\sqrt{1-n^2}$ given in equation 3. The time to complete a full period, that is through the time angle 2π, is T, where T is the damped period, and $T=T_0/\sqrt{1-n^2}$. The time angle for the deflection to A is therefore $(\pi-\alpha)$, and the time to reach A from zero is then

$$t_0=\left(\frac{\pi-\alpha}{2\pi}\right)T=\left(\frac{\pi-\alpha}{2\pi}\right)\frac{T_0}{\sqrt{1-n^2}}$$

which is the value of time by which the indicating instrument used in the noise meter is specified.

This time value for any completed instrument may be measured in several ways, for example, (1) by direct observation, using a high-speed electric stop watch; (2) by taking a motion picture of the motions of the pointer from which the time can be computed; (3) by applying an interrupted direct current, having the off and on times equal, and varying the speed of interruption until a maximum deflection of the pointer results. Then the time of a complete period, off and on, is equal to the damped period T, from which the specified time can be calculated from the equations given above.

Table I of this discussion gives the various constants of instruments having undamped periods from 0.5 to 0.7 second and damping factors from 10 to 100, computed from the above equations.

Table I

Undamped Period T_0 (Seconds)	Damped Period T (Seconds)	Damping Factor k	n	Deflection Time (Milliseconds)
0.5	0.62	10	0.592	217
0.5	0.885	100	0.825	357
0.7	0.87	10	0.592	304
0.7	1.24	100	0.825	500

C. W. Frick (General Electric Company, Schenectady, N. Y.): The measuring circuits described in the paper have been in use for a number of years with radio-noise meters according to the old specifications. In the testing of low-voltage devices both the line-to-line and the line-to-ground radio-influence voltages are measured. The following test illustrates relations which may be found between these quantities, depending on the conditions. It also shows reasons for making the two measurements. A commutator motor was set up with choke coils in the lines, each coil having 1,700 ohms reactance at 1,000 kilocycles. The frame of the motor was grounded. First the motor was tested on the standard circuit of figure 11 of the paper. The noise-influence voltage was 2,500 microvolts line-to-line (V_L) and 4,000 microvolts line-to-ground (V_0). Referring to the equivalent circuit in figure 7 of the paper, it appears that the internal voltages E_1 and E_2 taken with respect to ground are approximately equal in magnitude and in the same direction but not in phase, since when the line impedances are equal V_L is proportional to the vector difference of E_1 and E_2 and V_0 is proportional to one-half their vector sum. A later test indicates the assumption of equal magnitudes for E_1 and E_2 to be reasonable.

Next the device was connected in a circuit similar to figure 9 of the paper to try the effect of equal and unequal impedances between supply lines and ground. A delta network of 200 ohms between lines and 300 ohms from each line to ground, as in the paper, was used for the first condition. Noise voltage between lines was measured directly and noise voltage from line to ground was measured on the network of figure 12 connected as in figure 9. This gave 620 microvolts line-to-line and 1,080 microvolts line-to-ground. These values are approximately one-fourth of those measured according to figure 11, this ratio being the same as the ratio of the resistances of the networks which were 600 and 150 ohms respectively. This shows that the radio-frequency currents were controlled by the line chokes.

The next measurement was made with unequal impedances between lines and ground. One side of the line was connected to ground and a 150-ohm resistor was connected across the line. The measuring network of figure 12 was left in place. The noise voltages then became 1,250 microvolts line-to-line and 630 microvolts line-to-ground. It may be noted that the line-to-ground voltage is half the line-to-line voltage which it should be in this test because the network of figure 12 measures half the vector sum of the voltages between lines and ground and here the voltage on the grounded side is zero.

It appears from these results that the junction between E_1 and E_2 in figure 7 is practically grounded, probably through capacitances and the grounded frame. Then when one side is grounded it eliminates the voltage on that side from the circuit. The voltage across the line was the same with the ground on either side which would indicate that E_1 and E_2 are nearly equal in magnitude. In the case of equal impedances the line-to-ground voltage was proportional to half the vector sum of E_1 and E_2 or approximately proportional to either E_1 or E_2. In the case of one side grounded only one of these was acting and the voltage to ground was only half as large.

If the phases of E_1 and E_2 had been different the result would have been different. If they had been equal and opposite in direction instead of in the same direction, they would have tended to cancel each other out in the line-to-ground voltage when the impedances from line-to-ground were equal. However, when one side was grounded, eliminating either E_1 or E_2 from the circuit, the cancellation effect would not exist and the line-to-ground voltage would be about the same as in the test. Thus if E_1 and E_2 were opposite in phase the line-to-ground voltage would increase as it did in the test described in the paper. In the test described here, however, it decreased.

If E_1 and E_2 are opposite in phase, their effect is additive between lines. In such a case consideration of the test results indicates that under conditions of unequal impedances between lines and ground the line-to-ground voltage would not exceed half the value measured between lines provided the impedance of the line is not higher than the impedance of the network. The two quantities measured are useful for analyzing effects such as these.

In table I of the paper which gives an example of radio-noise data taken on a device and data taken in a home, the figures in the last three columns appear to be ratios between these two sets of measurements, but it is not clear what they are. It would be desirable for the authors to add an explanation of these figures and to show their use.

Further explanation would also be desirable in the case of figure 16. Can the shape of the curve for distorted voltage be explained? If the authors consider it necessary to take precautions to avoid errors attributed to voltage distortion, it would be desirable to state what these precautions should be.

Charles J. Miller, Jr. (The Ohio Brass Company, Barberton): The radio-noise meter described by the authors certainly has several desirable characteristics over those formerly available. The use of a logarithmic output meter with a range of 100 to 1 will certainly reduce the amount

of work necessary for measuring radio-influence voltages on all types of devices. The new meter will be direct reading, a decided improvement over the substitution method of measurement.

In connection with the proposed detector circuit and indicating meter, a tabulation of suitable combinations of R, C, and R_1 is given. The lowest value of R given is one megohm. Since this resistance is in series with the indicating meter, the sensitivity of this meter will have to be very high. The most sensitive portable meter with which the writer is familiar has a full scale deflection for 20 microamperes flowing through it. If used with the one-megohm resistor, the voltage across the capacitor C would have to be 20 volts to produce a full-scale reading. What is the maximum voltage that can be satisfactorily applied to the capacitor C, considering all the limitations imposed by vacuum tubes available, and what indicating-meter sensitivity is practical for this application?

The coupling circuit for use with high-voltage devices imposes three new limitations over the previous circuit. These are the upper limits placed upon stray capacitances on the bus side and potentiometer side of the circuit and the lower limit of 2,500 micromicrofarads for the coupling capacitor. A formula is given whereby one may calculate from the constants of the circuit, E_{R_1}, the voltage appearing across the resistance potentiometer. A second formula is given whereby the per cent error may be calculated if the load impedance into which the device is looking is different from a pure resistance. It is possible to determine all the constants of an existing circuit by measurements. While it is fully recognized that it is desirable to use a circuit meeting all the requirements, is it not practical to compute the error introduced by an existing circuit, whose parameters are known, and then to use this factor to correct all readings taken on that circuit in order to make them comparable with values that would be obtained on an ideal circuit?

E. T. Hughes (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): In 1930 the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA was appointed to study methods for improving radio reception and in particular to consider the steps necessary to co-ordinate this newer use of electricity with some of its other uses for light, heat, power transmission, and communication.

A major problem has been in the development of radio-noise test circuits for the laboratory measurement of radio-noise-influence voltages. A test circuit which could determine directly the radio-noise voltage to be expected on any receiver antenna from any electrical apparatus on test would be desirable. However, no definite method has been developed that will permit the calculation of the radio noise on a receiver antenna when the radio-frequency voltage produced by electrical apparatus is known. Therefore the solution to the problem has been to develop measuring circuits which will permit measuring the radio-noise-voltage output of electrical apparatus with a radio-frequency load simulating the load impedance of the power system. At the present state of the art the radio noise produced by any equipment can only be expressed in units measured, utilizing the coupling networks recommended by the joint co-ordination committee.

The two basic circuits which have resulted from these considerations have proved to be well adapted for laboratory work because it has been possible for investigators in different laboratories to obtain comparable results in tests on the same apparatus.

By the use of the high-voltage test circuit it has been possible for the NEMA members to recommend certain levels for various high-voltage equipments. These levels have been obtained by making measurements on new equipment and on equipment which was returned from the field. The establishment of permissible levels of radio-noise-influence voltage for all classes of apparatus will require a somewhat different approach to the problem through field tests on different systems throughout the country.

Field tests are now being conducted in the Pittsburgh area to aid in the establishment of levels for low-voltage appliances. An appliance will be tested for radio-noise-influence voltages in the laboratory, then installed in several different homes where the noise voltage on the antenna will be measured. Knowing the effective height of the installed antenna, the signal-to-noise ratio desired, and broadcast station field strength, then the tolerable noise-influence voltage will be:

$$V = \frac{Se}{R}$$

where

V = tolerable noise influence voltage
S = antenna noise factor
e = broadcast station field strength level
R = signal to noise ratio

It is expected that from these tests the antenna-noise factor for an average home may be determined.

A second set of tests has been planned on a 6,900-volt distribution system. These tests are intended to determine the attenuation, effect of reflection, the amount of radiated field, and the field intensity perpendicular to the line in terms of the actual high-frequency voltage on the transmission line. The attenuation of the noise voltage through distribution transformers will also be studied.

A comparison between the work on this subject here and abroad may be of interest to some. The noise meter conforming to the new committee specifications is very similar to the one adopted by England, France, Germany, Italy, and Belgium. The low-voltage coupling networks used in the United States are different in that we have adopted a star network compared to a delta circuit used abroad. Both networks, however, give comparable results when the impedances are the same. The joint co-ordination committee has adopted 600-ohm networks whereas the European network is 150 ohms. The reasons for adopting 600 ohms have been outlined in the paper.

The continuation of the work of the joint co-ordination committee shows promise of producing more beneficial results in the future and by universal adoption and use of this instrument and method of measurement, radio-noise levels for all types of equipment can be established.

C. V. Aggers, D. E. Foster, and C. S. Young: The supplementary information contained in the various discussions is a valuable contribution to the problem, making the paper a comprehensive description of the art of measuring radio noise.

J. J. Smith has raised the question as to why the instrument described in the paper differs from the specifications developed by the CISPR. The CISPR specifications call for a time constant on charge of 1 millisecond and on discharge of 160 milliseconds. The other differences between the instrument in the paper and the CISPR specifications are of a minor nature and will in general cause no difference in performance between the two instruments. In developing the specifications for detector time constants, consideration was given to the CISPR specifications. However, as pointed out in our paper, it is difficult to secure a charge time constant of 1 millisecond with available tubes and difficult to hold this value in production, whereas it is relatively easy to secure a 10-millisecond charge time constant and a time constant or such value may be more readily held in production of noise meters. The discharge time constant specified by the CISPR is of the same order as that of the indicating meter, and hence the indicating-meter time constant will have a large effect on the results obtained. By the use of the long time constant of 600 milliseconds suggested in our paper, a much wider permissible range of time constants for the indicating meter is provided, and indicating meters of more desirable characteristics may be secured. Furthermore, as pointed out in the paper, by largely eliminating the influence of the indicating meter, the effective discharge time constant becomes that of the circuit, and this may be more readily duplicated in production than the time constant of the meter. The ratio of charge to discharge in the CISPR specifications is larger than that of the meter described in our paper, and therefore the CISPR meter will give a higher indication on wave forms of the sharply peaked type. On wave forms approaching the sinusoid, the difference in indication between the CISPR and the joint co-ordination committee specifications will be of the order of one per cent, a relatively minor factor considering the other possible variations.

We feel that the time constants suggested in our paper will give more constant, reliable results and permit more uniformity in production of noise meters than those adopted by the CISPR.

C. M. Burrill points out that with the automatic-volume-control time constant suggested in our paper, the response on a single-pulse type of noise will depend in some degree on the time constants of the automatic-volume-control circuit. The response of the instrument will not be the true peak value on a single pulse or widely separated repetitive pulses, not only because of automatic-volume-control time constants, but also because of the detector time constants chosen. As pointed out in the reply to Doctor Smith's discussion, the detector

time constants were chosen to provide reliable and consistent results with practical tubes and circuits, rather than to provide idealized response to all types of noise. Furthermore, as pointed out in our paper, the disturbing effect of pulse types of noise appears to be less than would be indicated by their peak amplitude. It is felt that the correlation of the meter indication on such types of noises with their disturbing effects will be satisfactory with the time constants described and may in fact be better than when the time constants are chosen to give indications nearer the actual peak values. Mr. Burrill's suggestion of short automatic-volume-control time constants would be satisfactory provided adequate attenuation is provided by the automatic-volume-control filter having the short time constants he suggests. The automatic-volume-control filter must be such as to prevent the audio-frequency component of the noise present in the detector circuit from being applied to the amplifiers and there producing a modulation effect. An automatic-volume-control filter of short time constant with adequate attenuation of the audio-frequency component is considerably more complex, that is, must include more filter stages for the same attenuation, than one with a longer time constant.

Relaxation oscillators were considered in drawing up specifications on the noise meter, but experience to date with this type of oscillator was, in the opinion of the majority of the committee, such as to indicate that relaxation oscillators are not as reliable or uniform nor as readily checked in instrument use. The determination of the output of the relaxation oscillator by measurement of the supply voltage is an indirect method, and therefore not as accurate as measuring the current in a saturated diode. The advantage of a noise calibration source of a type to eliminate the selectivity influence in calibration mentioned by Mr. Burrill was also a factor influencing the committee's choice of a saturating diode as a noise source. Mr. Burrill is correct in stating that the theoretical shot noise from oxide-coated-filament tubes, such as are practical for portable noise meters, is not as readily determined as that from tungsten-filament tubes. However, in the noise meter described, oxide-coated-filament tubes are satisfactory, since they are used as a transfer standard, the initial calibration being in terms of an unmodulated sine-wave voltage. When so calibrated, it is felt that the oxide-coated-filament diode is a practical and uniform transfer standard readily determined by measurement of the space current. The difference between tungsten and oxide-coated, or thoriated-tungsten-filament tubes is that the latter two types do not have a sharp, definite saturation characteristic but saturate more gradually. Under such circumstances, the impedance of the diode must be taken into account. This impedance need not be specifically determined for the use described in our paper, since it is implicitly included in the initial calibration process.

C. J. Miller's comment emphasizes the point mentioned in our paper that a d-c amplifier may be employed to permit the use of a less sensitive meter. The use of a d-c amplifier and relatively insensitive meter is a more practical design combination than an attempt to secure a charge time constant of ten milliseconds with a resistor lower than one megohm. Battery-type tubes such as are required for portable noise meters have a rather high effective resistance when used to drive a diode and therefore consideration was not given to resistors of less than one megohm. All through the design of the instrument practical tube and circuit considerations were kept in mind in an endeavor to provide an instrument to give readily reproducible results.

The influence of capacitances in the measurement of high-voltage devices is perhaps more readily taken into account than might be indicated by Mr. Miller's comments. Such circuit capacitances are very important in television and have been studied by many investigators of late. The principles developed for television may be used in connection with other circuits where the stray capacitances are important, such as in this case the noise-measurement circuits. Among the several technical papers dealing with this problem, are the following:

"Analysis and Design of Video Amplifiers," S. W. Seeley and C. N. Kimball, *RCA Review*, January 1939.

"Transient Response of Multistage Video Frequency Amplifiers," A. V. Bedford and G. L. Friedendall, IRE *Proceedings*, April 1939.

These papers describe the principles and methods involved when uniform response characteristics are necessary over a range of the order of four megacycles, which is even greater than is required in the case of noise measurements.

J. J. Clarke inquires regarding means of making the noise audible. The provision for audible indication of the noise is a decided help in identifying the type of noise or in identifying broadcast stations when the equipment is used for field-intensity measurements. As pointed out in our paper, when the audio-frequency noise output is used for listening, the detector time constant should be of the order of 0.1 millisecond, which may be accomplished through the use of a switch reducing the value of the capacitor by a factor of 100 for listening purposes.

The specifications for the 150 to 18,000-kilocycle noise meter include a paragraph which states that a switch shall be provided to substitute for the weighting detector circuit a conventional second-detector circuit for carrier field-intensity measurements or to supply audio-frequency output which can be used for monitoring analysis with other apparatus.

Mr. Grimes pointed out the need for closer co-operation between the manufacturers and the field agencies. This has been one of the crying needs since the advent of radio but these two groups cannot co-ordinate their activities until standards on instruments and methods of measuring radio noise have been established. It will be only through the co-operation of these groups that sufficient data will be collected which will permit the interpretation of laboratory results in terms of expected radio noise.

It was pointed out by Mr. Hughes in his discussion that a series of field tests are contemplated in an attempt to obtain some conception of the correlation factor between laboratory measurements and field measurements. It is encouraging to note that such a program is under consideration. A number of such programs should permit the establishment of satisfactory radio noise levels for all types of apparatus.

The data included in Mr. Frick's discussion emphasizes the necessity for making both the line-to-line and line-to-ground measurements on low-voltage apparatus as well as choosing some definite terminating impedances for measuring the radio-noise-influence voltage.

The phase relation of E_1 and E_2 in figure 7 varies a great deal between types of machines and somewhat on even the same design of machines. The data shown in the paper is representative of what may be expected from a definite type of machine.

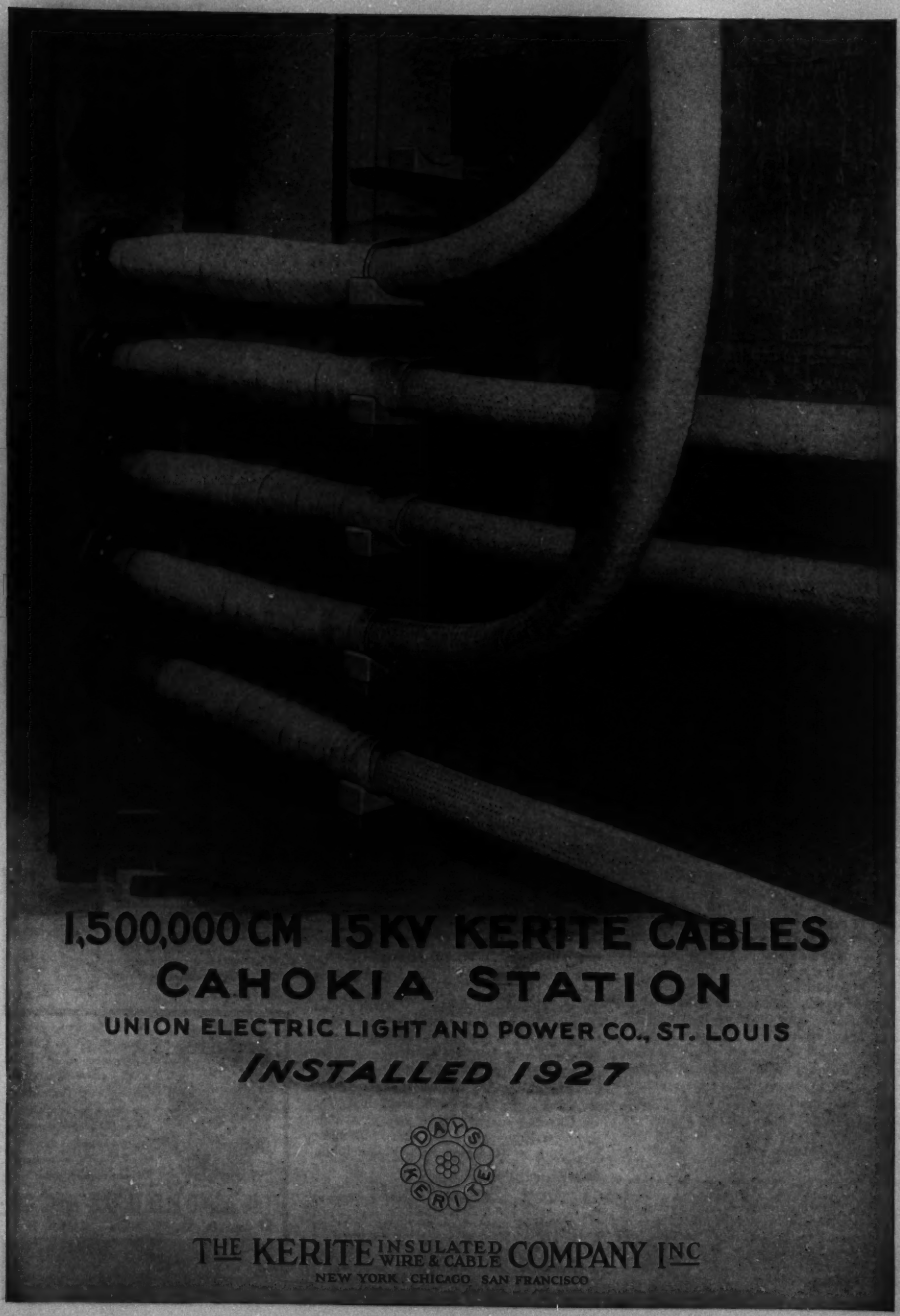
Mr. Frick stated that his tests indicated the junction between E_1 and E_2 in figure 7 is practically grounded. In practically all small commutating machines, the capacity of the windings to the frame is relatively small. There is also the impedance of the field winding between the interference generator and ground so that it would be practically impossible that the junction between E_1 and E_2 be at ground potential.

We wonder if Mr. Frick has not misinterpreted his results because if the measurement is made by figure 12 and one side of the line is grounded, the V_0 could be only half of the line-to-line voltage. In other words, the line-to-line measurement is actually the line-to-ground measurement because one side of the line is grounded. The value of 1,250 microvolts appears to be correct because in the previous measurement he obtained 1,080 microvolts line-to-ground. The grounding of one side should increase this value of 1,080 as was obtained by Mr. Frick.

Mr. Frick questions table I. The caption of the last three columns was omitted in the preprint. These columns give the noise voltage on the antenna in per cent of the noise-influence voltage line-to-ground and house wiring. The collection of this type of data by various investigators will permit the establishment of noise levels for such apparatus, for instance, at 610 kilocycles (table I) the noise voltage on the antenna is 8.9 per cent of the noise-influence voltage line-to-ground with the frame grounded. If, for example, it could be determined that an average of ten per cent of the noise-influence voltage produced by low-voltage devices would be obtained at the input to the radio receiver, then it would be possible to determine the permissible radio-noise-influence voltage of a device which would permit satisfactory radio reception with any available broadcasting field-strength level.

The distorted wave shape shown by figure 16 was due to drawing leading current through the induction regulator. In the case discussed, it was necessary to eliminate the induction regulator and energize the transformer from a motor generator set. From tests to date it appears as if it will be desirable to limit the total distortion of the voltage wave to five per cent.

Mr. Goodwin's discussion is a very valuable contribution on this subject as he has covered thoroughly many of the factors given consideration while preparing the specifications of the indicating meter for the radio-noise meter.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NEW YORK CHICAGO SAN FRANCISCO

Industrial Notes

Expansion Program for Standard Gas.—Construction of a 25,000-kw capacity addition to the Canal station of Louisville Gas & Electric Co., at Louisville, Ky., has been decided upon. Authorization of this project will result in a total of 160,000 kilowatts of additional generating capacity being under construction during 1940 by public utility operating companies in the Standard Gas & Electric Co. system, and appropriation for the Canal station addition brings the total tentative construction budget of the system for 1940 to over $40,000,000.

Roebling Appointment.—Edward D. Emerson, since 1937 district sales manager with Babcock & Wilcox Tube Co., New York City, has been appointed general manager of sales by the John A. Roebling's Sons Co., Trenton, N. J.

Lewis to Head Rectifier Division.—The manufacture and sale of selenium rectifiers in the United States has been placed in charge of George Lewis as manager of the rectifier division, International Telephone Development Co., with factory and sales headquarters at 137 Varick St., New York City. The selenium rectifier is manufactured exclusively in this country by the International Telephone Development Co., a subsidiary of the International Telephone and Telegraph Corporation. Mr. Lewis has played a prominent part in recent development work in the laboratories of the International associated companies in Europe, serving for a considerable period as commercial director of the large laboratory in Paris.

Roller-Smith Appointments.— C. Swain Lumley has been appointed district engineer of the Roller-Smith Co., Bethlehem, Pa., with headquarters in Chicago. He will cover the states of Michigan, Indiana, Illinois, Missouri, Iowa, and Minnesota, rendering engineering assistance to the company's sales agents in the territory. Mr. Lumley was formerly electrical engineer in charge of design on the Detroit new sewage treatment plant. From 1926 to 1935 he was designing mechanical-electrical engineer with Smith, Hinchman and Grylls, architects and consulting engineers, in Detroit. . . . . The Electric Steel Foundry Co., Honolulu, has been appointed as Roller-Smith sales agent for the territory of Hawaii.

Expenditures for WPA Electrical Equipment.—Electrical machinery, apparatus and supplies purchased for use on WPA projects amounted to $23,191,000 during the period from the program's inception in July 1935 through September 1939, according to figures released by the Work Projects Administration. These purchases were used on a broad variety of WPA projects including construction and improvement of public facilities in almost every major category. Total WPA purchases of materials, equipment and supplies of all kinds during the 1935–1939 period amounted to $1,118,764,000 and the manufacture and fabrication of these products required, according to Bureau of Labor Statistics' estimates, more than 2,565,000 man-months of employment.

Okonite Company Appointment.—Richard S. Hayes has been appointed advertising manager of The Okonite Co., Passaic, N. J., and The Okonite-Callender Cable Co., manufacturers of insulated wires and cables. Mr. Hayes joined The Okonite Company in 1925, and since 1936 has been in charge of various sales promotion activities.

WANTED: Experienced engineer for work on television studio circuits. Must be technical college graduate. Location, midwest. Address Box 192, ELECTRICAL ENGINEERING, 33 W. 39th St., New York City.

WANTED: Copies of the July (1939) issue of ELECTRICAL ENGINEERING. Please mail (parcel post) to American Institute of Electrical Engineers, 33 West 39th St., New York City, printing your name and address upon the enclosing wrapper. Twenty-five cents, plus postage, will be paid for each copy returned.

Trade Literature

Motor-Generator Sets.—Bulletin 502, 4 pp. Describes various types of motor-generator sets available in sizes up to 500-kw capacity. Reliance Electric & Engineering Co., 1088 Ivanhoe Road, Cleveland, Ohio.

Communication Home Study Course.—1940 Information Booklet, 32 pp. Describes a practical radio and communication engineering course designed for home study. Smith Practical Radio Institute, 1311 Terminal Tower, Cleveland, Ohio.

Cable Terminals.—Bulletin, 4 pp. Describes a new improved type of gasketless, soldered porcelain terminals, designed to be vacuum and pressure-tight in service, even under abnormal temperature and pressure conditions. The construction eliminates all gaskets and overcomes the problems associated with gasket leaks. General Cable Corp., 420 Lexington Ave., New York City.

Circuit Breakers.—Bulletin 4001. Describes a new, compact, type KB air circuit breaker which is capable of high speed interruption of currents far in excess of its conservative rupturing rating of 20,000 amperes, according to the manufacturer. Available in a variety of mountings, for electrical or manual operation, in ratings up to 600 amperes. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Penna.

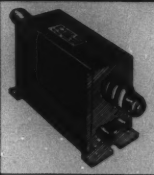
Distribution Transformers.—Catalog 40, 24 pp. Describes and illustrates a complete line of improved distribution transformers. Pocket type bushings are used on all such transformers up to 50 kva. The metallic parts of the primary bushings are porcelain enclosed, and these bushings incorporate a new mortise-type wire grip. The catalog includes transformer standards and tables for all ranges, and prices. Kuhlman Electric Co., Bay City, Mich.

Constant Voltage Transformers.—Catalog ACV-22. Describes constant voltage transformers capable of maintaining their output voltage to within a fraction of the per cent of the specified value, even though the line voltage varies as much as 30 per cent. Fully automatic, instantaneous in action, such transformers have no moving parts and require no maintenance; available in wide capacity ranges. Sola Electric Co., 2525 Clybourn St., Chicago, Ill.

Noise-Free Insulators.—Bulletin, 8 pp. Describes a complete line of "Quiet-Type" insulators for all operating voltages; illustrates the glaze-protected metallic oxides used in their manufacture. Such types are guaranteed to eliminate insulator radio-noise when installed on voltages for which they are designed. Included is a proposed table of permissible noise levels. The R. Thomas & Sons Co., Lisbon, Ohio.

A new list of available pamphlet copies of AIEE papers appears on page 10, adv. sec., this issue.

TRANSFORMERS



Luminous Tube transformers are only one of many classes of transformers that Acme builds. Because of variances in installation and application, this type of transformer must be built to endure much abuse.

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The General Radio Type 544-B Megohm Bridge with its 500-volt power supply is the ideal instrument for obtaining resistance-time curves of any generator. Its features include:

A-C OPERATION—portable (25½ pounds) no bulky dry batteries—no hand cranking of a generator

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TEST VOLTAGE AT 500 VOLTS D.C.—the standard voltage for measurements of this type

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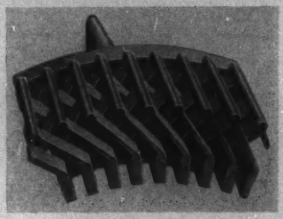
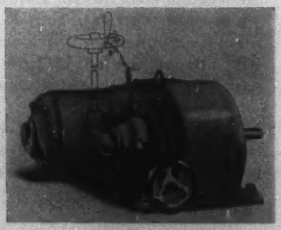
New Products

New Type Rotor Construction.—Offering the advantage of longer motor life with less maintenance, a new type rotor construction



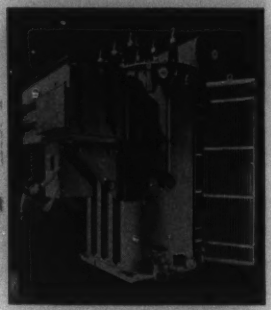
announced by the General Electric Company makes possible the use of cast-aluminum rotors in the larger sizes of double-squirrel-cage motors for high-starting-torque, low-starting-current service. Called the "Valv-amp" rotor, it employs a unique shape of rotor slot and a special method of assemblying rotor punchings to control the flow of starting current. As a result, without the use of a switch or other moving parts, current is permitted to flow in the outer squirrel-cage when the motor is started, thus producing high-starting torque. Then, when the motor comes up to speed, current is allowed to flow through the entire rotor "winding," resulting in excellent running characteristics. Above is an oblique end view, showing one arrangement of bars, end rings and fans.

Control for "Varidrive" Motors.—A new single, right angle, mechanical remote control for Varidrive motors has been developed

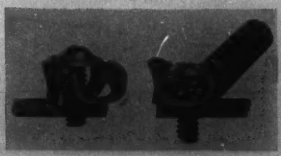


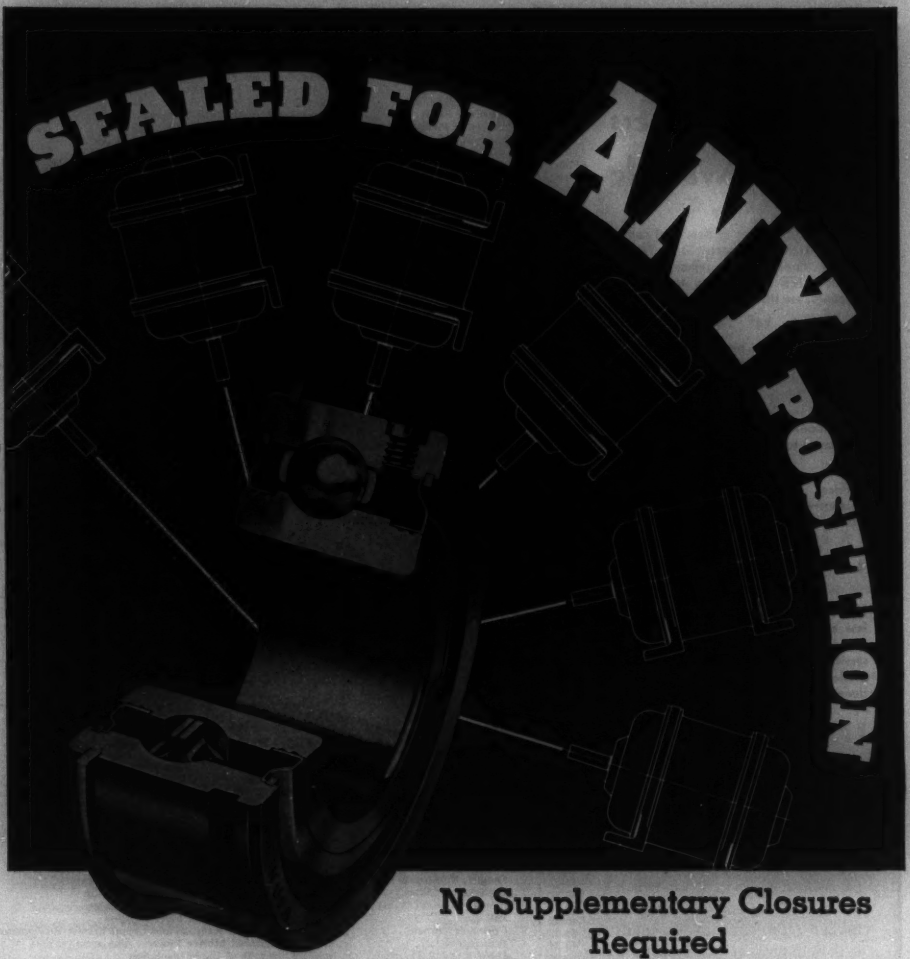
by U. S. Electrical Motors, Inc., of Los Angeles and Brooklyn. This control provides an accurate, simple means of selecting the desired operating speed of the motor when the Varidrive is mounted beneath or above the driven machine or is otherwise inaccessible. The control shaft may be extended at a 90-degree angle in any one of eight different directions, permitting the hand wheel to be placed within easy reach of the operator so that the exact desired speed can be maintained without difficulty at all times.

Load-Ratio Control.—The Allis-Chalmers Mfg. Company, Milwaukee, has introduced a new transformer load-radio control mechanism, known as type TLK, to supplement its already well-established types TLF and TLB. This new mechanism is designed for application on medium-large regulating and power transformers, single or three-phase, and can be arranged for automatic or manual control. The type TLK design has dial switches and rotary-breakers mounted on separate oil-filled compartments with complete mechanical interlocking so that the tap changing circuits are closed and opened by the breakers while changing taps. The illustration below shows the type TLK load-ratio-control mechanism mounted on a 3-phase regulating transformer for operation with an 18,750-kva, 35-kv circuit.



Connector.—This new solderless connector, developed by the Square D Company, Detroit, known as the Universal speed connector, will take from No. 14 to No. 4 wire. The connector is free to rotate around the screw, thus allowing wire to be inserted from almost any angle. This feature is important where large wires are used in a limited space. The unusual range in wire size permits the use of large wires for service drops to small 30- or 60-ampere switches. The connector is self-centering so that there is no need to wind the wire around the stud or to separate stranded conductors. As the screw is tightened, the lug is forced to one side and the wire is gripped tightly. When the tightening is completed, the screw exerts pressure against the wire on one side and the lug on the other side.





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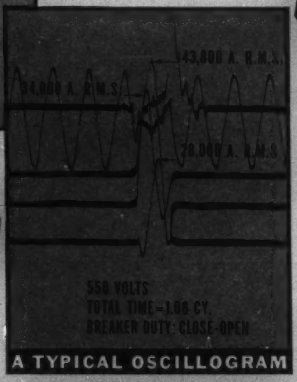
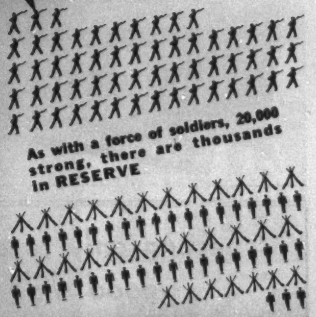


A TYPICAL OSCILLOGRAM

NOTE HOW SHORT THE ARCING TIME



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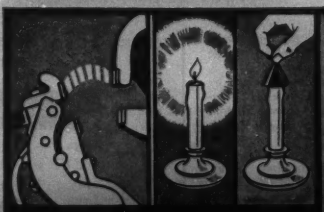

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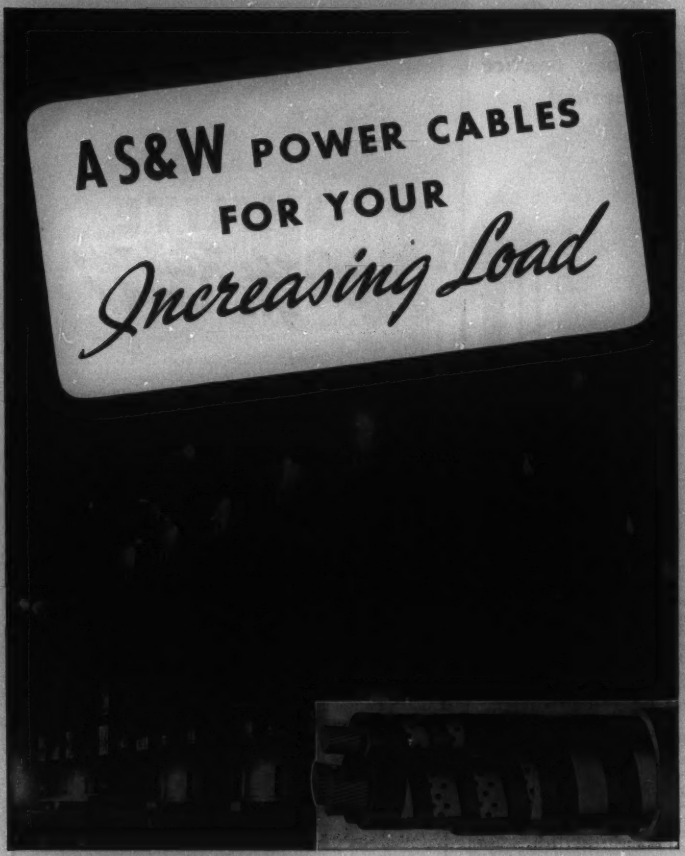

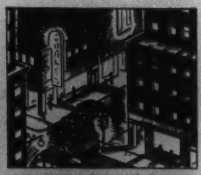

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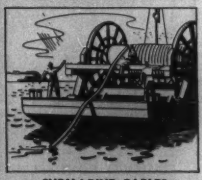

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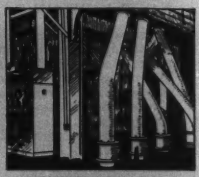

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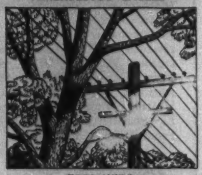

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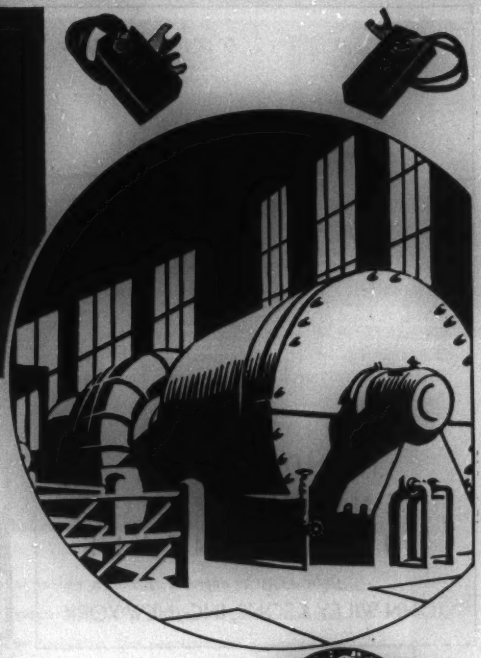

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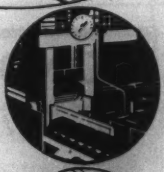

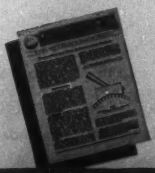

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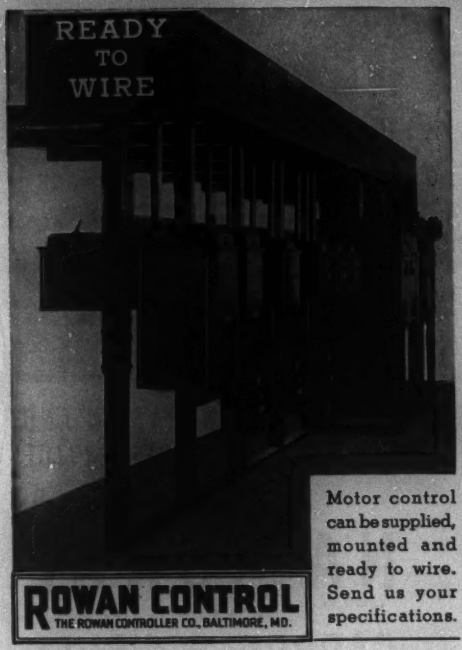

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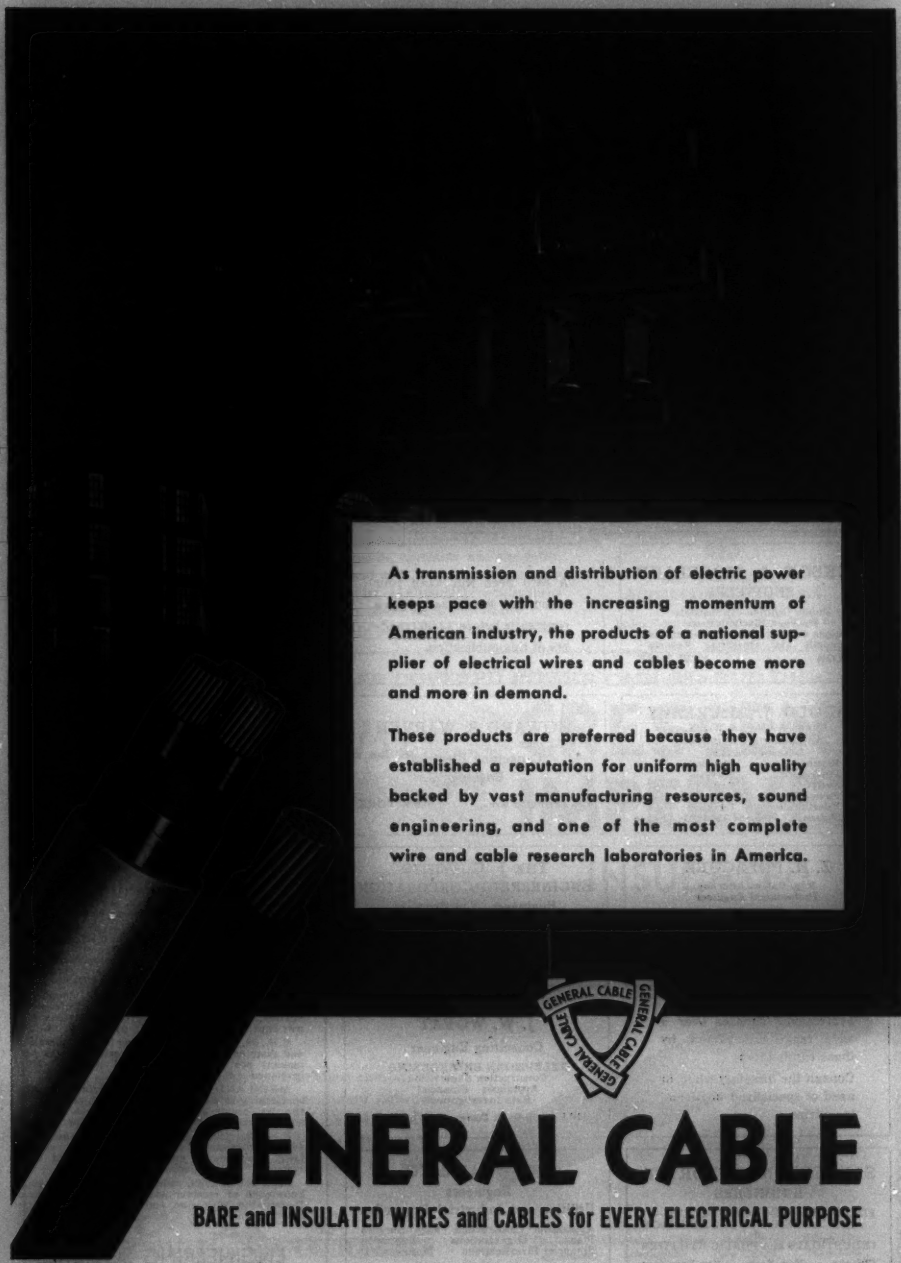

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M.S. in E.E., Univ. of Minn, 1938; 33, married; 18 mos exper pub util, asst to gen mgr; teaching exper; surveying exper; desires pos with engg future; now employed. E-601—261-Chicago.

PWR AND LT EXEC, 42, married; 20 yrs constr, oprn, maintenance hydro-elec, steam-elec plants and substations; 2 yrs Porto Rico. Location immaterial. E-602.

B.S., E.E., N.Y.U., 1936; 25, single; 3 yrs experimental lab, motors, generator and various apparatus; studying motor des; now employed, desires pos with elec. mfg or util with future. E-603.

B.S.E.E., Col City of New York, recent grad; single. Desires pos with mfr of elec or mech prod. Location immaterial, salary secondary. Available immed. E-604.

B.S.E.E., 1935, M.S., 1940; 26, married; Tau Beta Pi, honors. One yr devpmt test of fractional hp mach; 3 yrs asst instructor. Employed. Desires pos in teaching or indus devpmt. E-605.

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B.S.E.E.; licensed state, Dept. Commerce; married; 9 yrs des, devpmt, delicate electro-mech devices; elec testg; 5 yrs oprn marine steam-elec pwr eqpt; automatic control; pyrometry. E-608.

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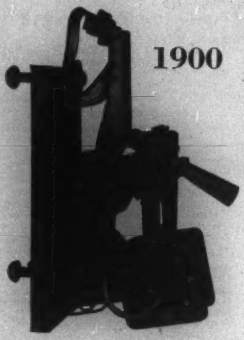

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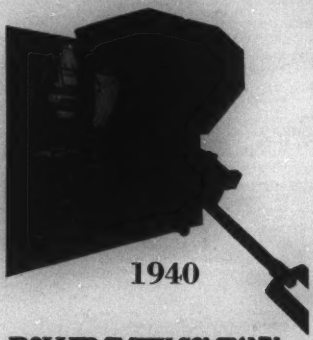

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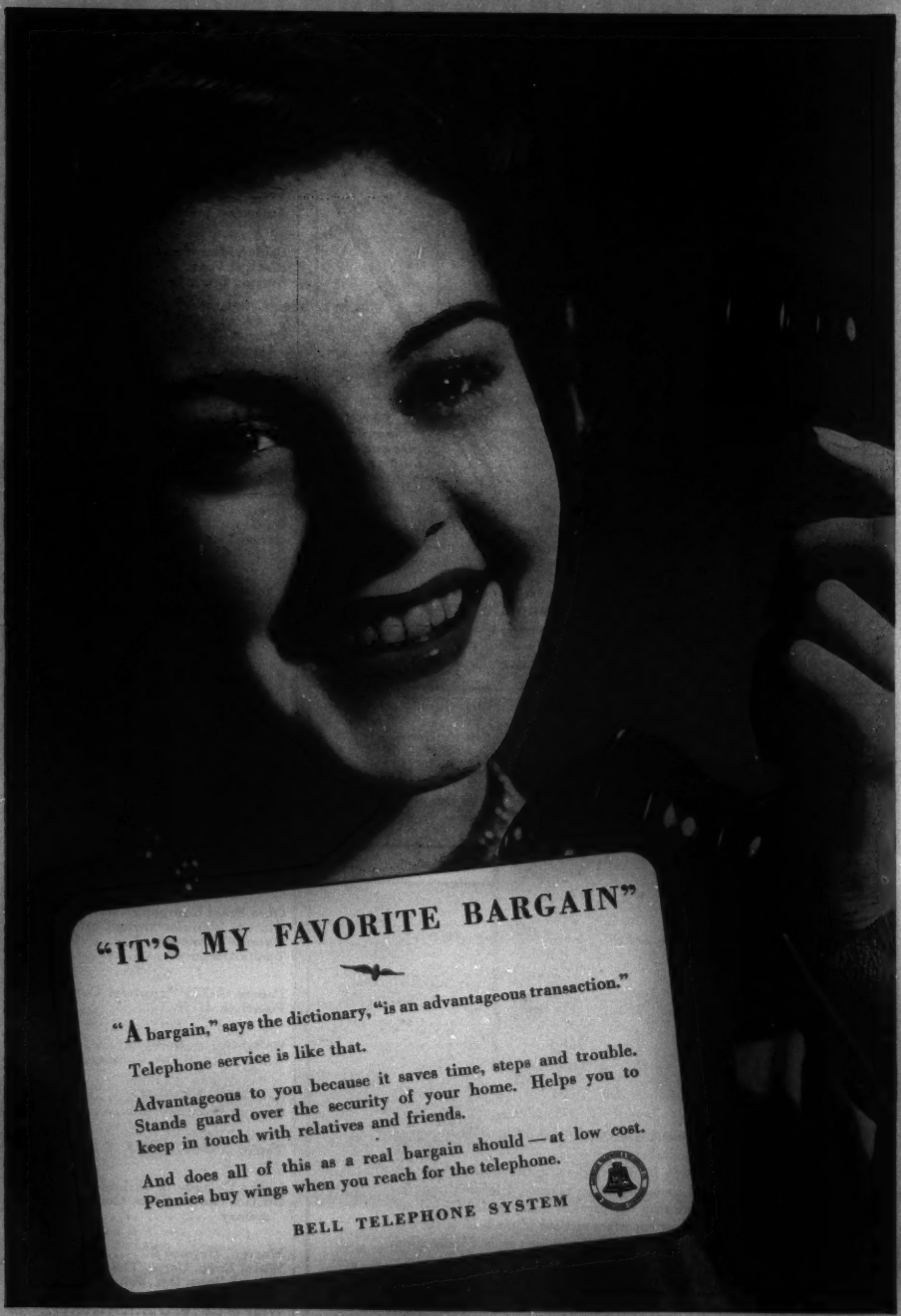
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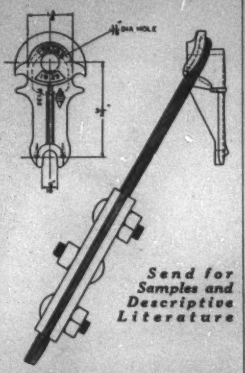

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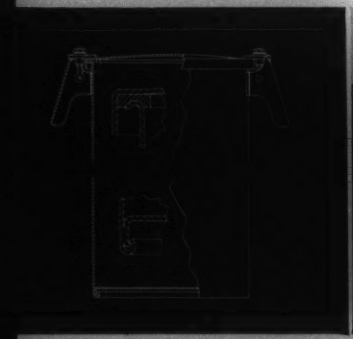

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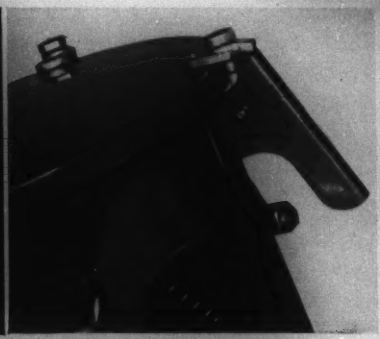

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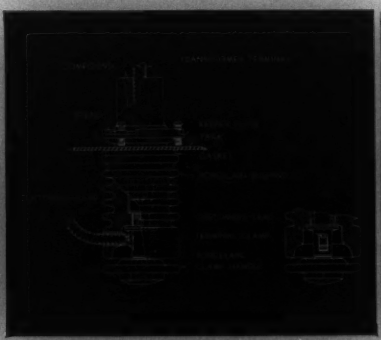
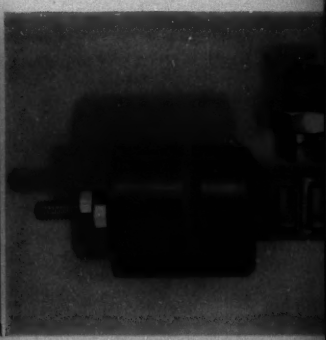
Pockets for Primary and Secondary bush ings are pressed directly into tank bod thus entirely eliminating welding, patc pockets or joints Entrance opening recesse providing gasket protection

The Kuhlman patented B. I. core and coil is standard on all Kuhlman distribution transformers from 1½ to and including 25 Kva, 2400 through 7620 volts.



Cross-section sketch of new Kuhlman pocket type primary bushing showing how all metallic parts are entirely surrounded by porcelain By turning knob at the end, the clamping mechanism opens or closes, freeing or securely gripping the line connection.



Low voltage secondary bushings showin split connector made in the form of a squar thereby bracing the middle leg which re ceives the connector This eliminates an chance of breaking or bending whe making a connection.

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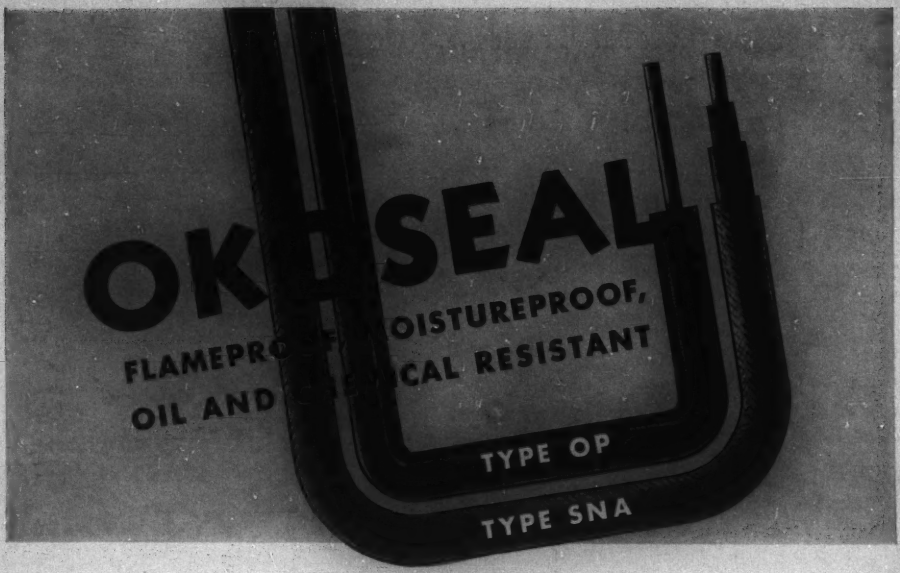

OKOSEAL INSULATED WIRES ARE APPROVED BY THE UNDERWRITERS LABORATORIES for the following applications:

TYPE OP Okoseal (without braids) is approved for switchboard use up to 80° C (176° F); maximum working voltage 600 volts. Available in colors.

TYPE OP Okoseal wire is also approved for use in appliances or in recognized metal raceways which do not permit the use of the usual types of insulation, specifically where exposed to oil, and a temperature not exceeding 60° C (140° F), and in accordance with paragraph 3004h of the 1937 National Electrical Code.

TYPE SNA switchboard wire (with felted asbestos and braid covering) is approved for still higher temperatures. It can be used where the temperature does not exceed 90° C (194° F); maximum working voltage 600 volts.

DEVELOPED for use under conditions which do not permit the use of usual types, this synthetic insulation possesses the following remarkable characteristics — Heat resisting . . . flameproof and will not support combustion . . . tough, resists abrasion and yet so pliable it bends around sharp corners . . . so moistureproof that it withstands months of immersion with dielectric strength unchanged . . . leather-like in texture with a smooth finish . . . used as insulation up to 600 volts or as protective sheath on higher voltage. Write us for further information on Okoseal wires.

THE OKONITE COMPANY

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EXECUTIVE OFFICE: PASSAIC, NEW JERSEY

HAZARD INSULATED WIRE WORKS DIVISION

THE OKONITE-CALLENDER CABLE CO., INC.

SALES OFFICES IN PRINCIPAL CITIES

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